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A DEMONSTRATION OF THERMAL WATER UTILIZATION IN AGRICULTURE

James W. Berry, et al

Eugene Water and Electric Board

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16. Abstract

A five-year demonstration project was conducted to determine benefits and identify harmful effects of using waste heat in condenser cooling water (90°F-110°F) for agricultural purposes.

Initial phases of the demonstration emphasized the use and evaluation of warm water for spring frost protection, irrigation, and plant cooling during summer. Various row crops and fruit and nut trees were included in the evaluation.

Undersoil heating was demonstrated on a 1.2 acre soil plot. Two and one half inch plastic pipes were buried 26 inches deep and 5 feet on center, connecting to 6 inch steel headers. Warm water was circulated through the grid, heating soil on which ~~row~~ crops were grown.

A plastic greenhouse (22' x 55') was constructed on a portion of the undersoil heat grid. Greenhouse crop production was thoroughly evaluated.

Conclusions indicate that the greatest potential benefit of waste heat use in agriculture is in the area of greenhouse soil heating. Monetary benefits from industrial waste heat appear achievable through proper management. (Christianson - EPA)

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A DEMONSTRATION OF
THERMAL WATER UTILIZATION
IN AGRICULTURE

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ABSTRACT

The five-year thermal water demonstration project described in this report was designed to determine benefits and uncover any harmful effects related to thermal water's application in agriculture. The water's temperature approximated that which would be expected from fossil or nuclear power stations and other industrial plants. Benefits were explored in the following areas: frost protection, undersoil heating, greenhouse applications, double cropping, plant cooling, and humidity control.

Benefits to agriculture of the water's heat content are described; no detrimental effects were uncovered.

This report is submitted in fulfillment of Grant S802032 by Eugene Water & Electric Board under the partial sponsorship of the Environmental Protection Agency. Work was completed as of May 31, 1973.

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* Listed in order of Project farm sites:

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James B. O'Brien	Farm 2
Rex Heide	Farm 3
W. William Puustinen	Farm 4
William L. Cole	Farm 5
Dale Bartholomew	Farms 5 & 6
Robert W. Bennett	Farm 7
Virgil Nave (Present Owner)	Farm 7

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CONCLUSIONS

GENERAL

Today we are experiencing a rapidly expanding population; agriculture and the development of energy resources are being forced to keep pace. Wise utilization of water will be a key factor in this expansion. It is clear that multi-use of this resource will be a necessity.

Agriculture's reuse of warm industrial water holds much promise in the scheme of expansion since it will transform what appeared to be an environmental threat into a beneficial influence. This project has demonstrated several of the agricultural benefits to be derived from the heat content of thermal effluents and has found no detrimental effects. Water, after having been used for irrigating the Springfield project, has been returned to the McKenzie minus the industrial heat; this in itself is highly significant when one considers the enormously expensive cooling procedures currently being employed by the electric power industry--procedures that totally waste the heat.

The cooling-lake method of cooling thermal effluents is likely to emerge as thermal-water agriculture comes to the fore. The multi-use possibilities for the water in such a lake are exciting. Surrounding municipalities, agriculture, industry, power producers, and public recreation could all mutually benefit from such a body of water.

Specific methods have been demonstrated for using warmed condenser cooling water for agricultural purposes. For some applications, i.e., irrigation and plant cooling, such water does not offer significant benefits which can be attributed to its elevated temperature alone; conversely, no damage need be incurred. For frost protection, warm water appears to offer advantages over water at normal temperatures.

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Warm water use for underground soil heating, in open fields and under greenhouses, shows significant potential for profitable use with selected crops which demonstrated increased yields.

FROST PROTECTION

Significant accomplishments were achieved on this project in demonstrating warm water use for frost protection.

The result of warm water frost protection was a reduction in frost damage and crop loss, particularly for orchard crops under warm-water application. For example, no fruit buds in thermal-water-protected orchards were damaged by spring freezes. A full crop of peaches was produced in the project orchards. Unprotected orchards in the surrounding countryside produced no crop to a very light crop of peaches.

It can be concluded that thermal-water spray for frost protection has several advantages over cold-water spray because less water is required when the water is warm. It was observed that there was no temperature depression when sprinklers using thermal water were turned on for frost protection. Since no depression was noted, sprinklers could be activated very close to critical bud temperatures. Thus, much less water was applied than if sprinklers had been activated every time the temperature fell to 33°F as suggested in the literature for cold water. Temperature profiles indicated that thermal water apparently compensates for the evaporative cooling effects as the water leaves the sprinkler, so no initial temperature depression occurs. Less limb breakage, lower water costs, and reduced nutrient leaching from the soil are among the benefits to be derived from this reduction in water volume.

An important factor in frost protection is the availability of precise data on specific bud development stages and critical bud temperatures. During the project's final frost-protection season, published data for farmers became available through the Washington State University

Agricultural Extension circulars that pinpoint these stages and related temperatures. This information also reduced the amount of water applied to the crops and reduced the amount of spraying and dusting required for insect and disease control.

Both above- and under-tree sprinkling was evaluated; it became evident through project demonstrations that under-tree sprinkling with warm or cold water is not satisfactory for frost protection.

UNDERSOIL HEATING

The results of the underground soil heating and greenhouse demonstrations are considered among the most significant revelations of this project in terms of potential applications for waste heat.

The effect of the warm water grid on soil temperature was most noticeable directly above individual heating pipes; the effect also increased with depth and varied throughout the seasons of the year. At the 1-in. depth, temperatures were not affected much during summer; for the rest of the year, the increase was from 0.5 to 4°F. At the 6 in. depth, maximum temperature increases averaged 4.8°F based on measurements from January 1972 through March 1973. For the same time span, increases at the 12 in. and 24 in. depths were 7.8°F and 8.4°F, respectively.

Soil temperature increases on the heating grid portion covered with the plastic greenhouse were higher than on the uncovered heat grid described above. The maximum temperature increase in the greenhouse at the 6 in. depth averaged 9.5°F above control. At the 12 in. level, the average increase was 11.2°F. At the 24 in. level, temperature increases averaged 20.7°F.

Air temperature was also significantly increased in the greenhouse due to the soil warming. Greenhouse minimum temperatures averaged 8.2°F higher than ambient minimums. These temperatures indicated the effect of the added heat since natural greenhouse solar heating would not influence night-time minimums to a great extent.

Effects of soil heating on crop production were assessed for a number of plants including tomatoes, sweet corn, asparagus, rhododendrons, cantaloupes, and squash. Not all crop production was affected significantly, although differences were almost always noted in various growth stages.

The demonstrations with various crops indicated that the closer the roots are to the soil heat grid, the greater the effect on growth. In illustration, the roots of one-year-old asparagus crowns are relatively shallow; crown production was not influenced by the soil heat grid to this age. In contrast, two-year-old asparagus crowns, with more developed root systems, produced about 50 percent more fern growth on heated soil. The production of early spring asparagus spears was also stimulated by soil heat; yields increased by 44 and 95 percent in terms of number and weight of spears, respectively.

Accelerated root development of rhododendrons was noted on heated soil. This nursery stock was ready for market approximately one year sooner in some cases. Quantitative data were not gathered on this accelerated root development, but the quantitative results indicate that significant benefits may be derived. Further demonstrations are needed with ornamentals and tree crops.

Greenhouse crop production was also assessed for leaf lettuce, tomatoes, and cucumbers. Results are presented in terms of absolute production potential from the soil-heated greenhouse rather than in comparative terms involving control plots.

Production results and estimated cash values were also determined for lettuce and cucumbers. Of the greenhouse crops cultivated, Japanese salad cucumbers exhibited the greatest potential for profitable growth. The minimum wholesale value of this variety of cucumber, based on the project's greenhouse production and current wholesale prices, would approach $100,000 per acre.

Optimum soil temperatures for most crops are not known. Lack of response to soil heating may not necessarily indicate that soil heat is not beneficial for a particular crop. The thermal-water grid did not appear to improve the yield of 'Fireball' and 'Willamette' tomatoes. It is likely that location of the test plantings and the growing season affected the results.

The undersoil-heated greenhouse has demonstrated a good return on investment utilizing selective cropping and a 12-month period.

HEAT EXCHANGE WITH AIR, SOIL, AND PLANTS

At night during the growing season, the project's ambient air temperature often dropped below the optimum level for plant growth. Thermal water was applied during these cooler nights to determine if the air temperature could be raised to a more beneficial level. It was determined that no measurable rise in air temperature occurred.

Selected measurements were made at various levels up to 40 ft to better define local meteorological effects of water applications, and its effects on microclimatology.

In May and July of 1969, it was demonstrated on the project that thermal water cooled approximately 2°F per foot distance it traveled from the sprinkler nozzle during periods of low relative humidity. This was in line with the findings of C. H. Pair that, during periods of high ambient air temperatures, water in excess of 100°F at the sprinkler nozzle may be below ambient air temperature by the time it reaches the plants.

Thermal water can serve as a plant cooling agent in two respects: 1) it is cooler than ambient air temperature in contact with the plants; and

2) it increases the wetted surface area increasing evaporative cooling in the plant environment.

Plant cooling was applied when plant temperatures exceeded 86°F, which is near the temperature at which plant growth decreases and where plant injury may occur through excessive transpiration. During periods when plant cooling was demonstrated, temperature decreases from 4 to 6°F and relative humidity increases up to 20 percent were recorded in sprinkled areas.

The rate and amount of heat penetration in the soil were closely related to the volume and temperature of the applied water. Temperature alterations caused by irrigation water take place slowly at depths of 12 in. or more. Soil temperatures at the surface, however, were rapidly modified.

Although no plant damage was noted on project soy beans and tomatoes irrigated with 108°F, some varieties may be more sensitive to surface thermal-water application.

IRRIGATION

The experiments with sprinkler and furrow irrigation showed that warm water may be used for this purpose without adverse effects, if properly managed. Soil temperatures were raised by warm water applied in furrows; the rate and amount of heat penetration was closely related to volume and temperature of water applied. Under normal applications, the soil heating effect is rather short-lived. No significant benefit to plants could be associated with the presence of waste heat in irrigation water, except that plant life did not enter a cold thermal shock.

FUNGI, MOLDS, AND BACTERIA

No increase in fungi, mold, and bacterial infestation was noted on the project in any of the crops irrigated with thermal water.

ECONOMICS

The project, after five years of operation, has completely demonstrated the feasibility of thermal water's use for frost control, irrigation, plant cooling, and undersoil heating.

Total cost for installation of the pumping system, buried main line, laterals, and above-ground solid-set system, including high risers for the 70 acres of orchard for frost control and 100 acres for row crop plant cooling, was $220,000; this figure includes many costs that would not be associated with a normal agricultural system not used for demonstration. An estimate obtained from Western Irrigation Manufacturing, Inc., Eugene, Oregon, indicates that a multi-use system would cost $675 per acre with an on-site source of water. On 170 acres, the total initial cost would be $114,750. Using a capital recovery factor of 0.1359* and an estimated life of ten years, the annual fixed cost of the facilities (excluding taxes and insurance) would be $15,594.33. This amounts to an annual cost of $82.81 per acre for a solid-set, multi-use system.

A first approximation of the cost of frost protection and irrigation by other methods must be compared to the costs of a multi-use system. Since a system purchased for irrigation (but not frost control) is usually moved from setting to setting, plant cooling would not be feasible. A hand-move system would cost approximately $150+ per acre, or $25,500 for a 170-acre horticultural plot.

Of the commercially applied orchard heating systems for frost protection, the central distribution system is rapidly gaining popularity because of its effectiveness and nonpolluting characteristics. A price of $525 per acre covers the equipment and installation costs of a typical central distribution system.* Operation costs are frequently as high as $7 per hour per acre.+ In addition to the fuel costs, these systems have an increased labor cost (see Appendix A, Table A-1, page 204).

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* Based upon 10-year amortization at 6 percent interest

+ Estimate obtained from Western Irrigation and Manufacturing, Inc.

Solid-fuel systems such as "brick" and wax heaters have very low installation cost but high operation costs because of the nature of the fuel. A figure of $50 to $75 per acre per night of protection is not uncommon.‡

An approximation of the total annual fixed cost for the above-mentioned three types of systems is given in Table A-1. The multi-use thermal water system has slightly greater annual fixed costs but can also be used for plant cooling and irrigation. Because of the initial outlay for equipment, the solid fuel plus irrigation system approach has a nominal annual fixed cost per acre.

An approximation of annual operational costs per acre are shown on Table A-2 (page 205).

Although the solid-set multi-use system may have a higher annual fixed cost, the annual operational costs are considerably less, equaling approximately 1/25th the costs of the other systems.

Combining the annual fixed and operational costs (Tables A-1 and A-2) of the various systems, the total annual cost is approximated (Table A-3, page 206). While figures are based on best estimates and realistic assumptions, they would vary somewhat from area to area since each area has its own unique characteristics and problems. Nevertheless, the cost comparisons are accurate. The multi-use thermal water system would be approximately 33-1/3 percent as expensive as other various systems combined to provide frost protection and irrigation. In addition, the multi-use system is the only one capable of providing plant cooling.

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* Figures derived from literature by Spot Heaters, Inc.

+ Based upon 40 heaters per acre burning 1 gal per hr of No. 2 diesel fuel at 17-1/2¢ per gal.

‡ Based on advertisement and articles in February 1968 and February 1971 AMERICAN FRUIT GROWER, Western Edition.

Although the cost estimates of the multi-use system have been based on the actual installed costs of the pump and the closed-pressure underground piping conduit, the possibility of financial or technical assistance from industry in utilizing this method to overcome their potential thermal water pollution problems has now been established during this five-year program.

Based on research development work performed by L. L. Boersma at Oregon State University, utilizing electrical heating cables to induce heat into soil, a PVC 2-1/2 in. pipe grid was designed and installed to further demonstrate that thermal water from an industrial plant could be used to allow twelve months of horticultural cropping.

The total installed cost of the undersoil heating system was $14,550 and covered an area of 83,000 sq ft. Included in the installation cost was special instrumentation inserts and valves.

A normal field installation of undersoil piping, using PVC pipe, 2-1/2 in. diameter, buried 26 in. with 60-in. center spacing, would cost $7,000 per acre. Using a capital recovery factor of 0.1359 and an estimated life span of ten years, the annual fixed cost of the system (excluding taxes and insurance) is $111.30 for one acre.

In the Willamette Valley, the climate is relatively mild and year-around cropping is possible when a greenhouse is placed over the soil heated area.

The cost of constructing a plastic greenhouse depends on the length of service a grower desires from the structure. Using pressure-treated structural-grade lumber and plastic film (UV Poly), a rigid frame greenhouse would cost $1.129 per sq ft.

Based on the above costs shown in Table A-5 (page 208), the total cost for a one-acre greenhouse would be $49,179.24. Thus, the total cost for undersoil heating and greenhouse would be $56,179.24. Using a capital recovery factor of 0.1359 and a life span of ten years, the annual fixed cost of the one-acre installation (excluding taxes and insurance) is $7,633.75.

Using actual crop harvest results from the greenhouse/undersoil heat installation and selected varieties of produce, the gross returns for a one-acre installation (starting with lettuce transplants on March 8, 1972, and ending with final harvest of Japanese salad cucumbers and tomatoes on September 12, 1972) are as shown in Table A-6, page 209; see Section VI for more detail.

Although for test purposes both Japanese salad cucumbers and tomatoes were raised simultaneously, it must be recognized that, for calculation of minimum and maximum returns per acre, both crops encompass the same growing period. Therefore, one of the crops, tomatoes, has been eliminated from the calculation of gross returns.

It follows that the gross return per year, with selective cropping, could be at a minimum of $161,837 and a maximum of $288,809 for a nine-month operation (see Table A-7, page 210).

RECOMMENDATIONS

It is recommended that industry and agriculture apply the findings of this project to help eliminate thermal pollution of our waterways while benefiting agriculture.

The demonstration project has yielded much useful data relevant to the economic analysis of thermal water application in agriculture. Extensive analysis is now possible through comparisons of thermal water farming capital costs, operating costs, and farm yields with those of non-thermal farming. Project data should now be applied within comprehensive analysis formulas and computer models.

A fruitful area of investigation will be the cost comparisons of heat dissipation partially or wholly through agricultural applications versus those associated with dissipating heat totally by conventional cooling devices. Thermal power plant siting will also affect these costs.

Examination of the costs, benefits, and environmental influences of thermal and geothermal power sources as related to agriculture, fisheries, and recreation should be an extension of this study.

Experience on this project suggests that there is significant potential for undersoil heating in the production of a wide range of high-value ornamentals and flowers. Root development responds favorably to soil heat for many woody plants such as rhododendrons. This effect should be evaluated for various crops of this type to quantify growth enhancement leading to quicker marketing.

Maximum beneficial temperatures of water need to be established for each crop grown under thermal water; the ideal soil moisture levels for undersoil heat transfer also need to be determined.

Undersoil heating demonstration with young trees destined for reforestation programs is also an area of promise since transplant mortality might be reduced by better root development. A study should be conducted by a college of forestry or appropriate commercial organization to determine the effects of warm water soil heating on the growth of young deciduous and conifer trees.

Systems for using and controlling waste heat should be refined to enable design capability for meeting specific requirements at minimum costs. Monitoring systems should also be refined for cost minimization.

Frontispiece: The Thermal Water Project on the McKenzie River

SECTION I

INTRODUCTION

BACKGROUND

Many estimates have been made concerning United States electrical power demands from the present to the year 2000. A 5-percent annual growth rate has been suggested, which would mean that energy availability must double every 14 years. Many utilities are predicting that energy availability must double every 10 years.

We are even now seeing a proliferation of new generating facilities across the land and rising concern over the affect they will have on the environment. In the nuclear power sector alone, there were 29 nuclear plants operating, 55 being built, and 76 on order at the end of 1972.

The Environmental Protection Agency estimates that the U.S. will require approximately 200 billion gallons of fresh water daily to cool the condensers of the plants required to produce the two thousand billion kilowatt hours needed by 1980. Such water will be essentially free of contaminants, but it will be discharged at 90 to 120°F. Direct release to fresh water or marine environment might cause biological pollution because of the heat content. Thus, these industrial waters must be cooled before they are released, and such cooling will be a task of major proportions because of the prodigious quantities involved (500,000 gallons a minute, or more, from one 1000 megawatt nuclear plant).

Current effluent water cooling for most plants in the 1000 MWe range is through the use of cooling towers where effluent heat from the water is dispersed to the atmosphere.

This cooling procedure is extremely expensive (a tower initially costs approximately $10 million and has a high annual operating cost) and, significantly, the heat is wasted. At the time of this project's inception, the Eugene Water & Electric Board felt that possibly systems could be developed whereby heated industrial effluents would serve agriculture as they were being cooled, thus turning a liability into an asset.

New power from hydro-electric dams is no longer available in the Northwest. Soon the Columbia River will be navigable slack water from the Pacific Ocean almost to the Canadian border.

Many spokesmen for agriculture, government, and educational institutions now envision plans whereby the joint development of thermal power with irrigation could eventually bring water to many thousands of dryland acres in the Northwest. The effluent from one 1000 MWe nuclear reactor could under optimum conditions be used to irrigate 100,000 acres with four acre-feet of water.

Between 1965 and 2010, agriculture in the Pacific Northwest is expected to increase from 6-1/2 million to 17 million acres if water is made available. The population will increase from 5 million to 14 million. Irrigated acreage expansion in the 1970's is predicted at 175,000 acres per year.*

Mutual development of power and irrigation could substantially increase agricultural output while lowering power costs. One facet of such a multi-use approach would be the sale of necessary power to agriculture for pumping. The irrigation of 100,000 acres would require some additional 35,000 hp of connected load to power pumps on the irrigated farms.

* Bonneville Power Administration Power Distributors, 1966 Report.

EARLY EVOLUTION OF THE PROJECT

The five-year thermal water project was originally tied to the premise that a nuclear power generating plant would be erected at the south end of the Willamette Valley. The plant, utilizing the latest pressurized boiling water reactor concepts, was to have a capacity of between 1100 and 1250 megawatts, and its condenser cooling water requirements were to range between 500,000 and 850,000 gallons of water per minute. The cooling water temperature increase after passing over the condenser was to be from 17 to 33°F.

The Board of Directors of EWEB directed the manager and his staff to form an internal planning and coordination group which was to assess the various impacts of the plant--such as, regional growth and development, economic influences, agriculture and industrial growth, urban development, recreation, and environmental influence.

In its early review of impact, EWEB coordinated its efforts with Lane County, the State of Oregon, the Pacific Northwest electrical industry, the Edison Electrical Institute, Public Power Association, and the federal agencies involved in producing and transmitting electric power (i.e., Bonneville Power Administration, Bureau of Reclamation, Corps of Engineers, and the Soils Conservation Service of the U.S. Department of Agriculture*).

As part of its overall environmental review, EWEB was considering some of the multi-use potentials of the future plant's thermal-water effluent; thermal-water irrigation was one such use.

Dovetailing at that time (1967) with EWEB's efforts to assess environmental influences of a power station was a proposal by seven farmers near Weyerhaeuser's Springfield mill. The farmers offered the use of their land with its orchards and row crops as a demonstration area if EWEB would establish and maintain an irrigation system which would transport industrial thermal water from Weyerhaeuser to their properties. Weyerhaeuser water, at that time, was being discharged directly into the McKenzie River. This water approximated the temperature of cooling water flowing from power stations. After this reuse, the cooled water would be returned to the McKenzie River in a manner and at a temperature satisfactory to both environmental interests and sport fisheries associations.

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* The USDA is responsible for administrating the Small Water Sheds Act, which has jurisdiction over irrigation and water management of the Willamette River Basin.

Along with the gathering of data on thermal water use and its effects on the environment, the project was to demonstrate the ability of industry, farmer, engineer, and federal and state agencies to work in close cooperation to bring this new complex idea to a successful conclusion.

EWEB's management selected Vitro Engineering to perform a feasibility study on the possibilities of utilizing water from a thermal plant that would meet the necessary requirements of all participants. Included in the feasibility study was the outlining of Vitro's capability to establish a program which would accommodate the climatological factors of the South Willamette Valley and to establish advantageous agricultural schemes to demonstrate the multiuse concept for eventual betterment of the 110,000 acres in the upper Willamette. After several months of study, Vitro reported that the project was not only feasible but practical. Early in 1969, project construction commenced. Four months later, thermal water was being applied within the demonstration acreage.

Limited irrigation with waste water had been tried in Oregon as far back as the late thirties when several towns tried using waste from primary sewage-treatment plants to water crops and pastures. Public reaction soon limited those efforts to pasture land, but the idea slowly built as industry picked it up to solve waste-discharge problems.

In 1957, water from Weyerhaeuser's Springfield mill was sprayed on pasture land. This waste water was hot and it carried considerable organic materials and, in general, was not desirable for direct discharge to the McKenzie

River. This irrigation served to cool the wastes and deposit the organic material on the ground, where it was consumed by soil bacteria; the water, in a cleansed condition, filtered back through the soil into the river. Arthur King, a conservation specialist at Oregon State University, was closely involved with this application of Weyerhaeuser water.

EARLY SITING PLANS

Based on "Oregon's Long-Range Requirements for Water" that was prepared by the Oregon's Water Resources Board, it was estimated that the diversion requirements in the year 2070 would be 4.3 acre-feet per acre for all areas found to be suitable for development and that the irrigation requirements would be 2.1 acre-feet per acre to support agriculture within the Willamette and Sandy subbasins. The gross water requirements would be 4,073,000 acre feet. The return flow would be 543,000 acre-feet per year.

The consumptive use for irrigation was estimated to be 3,530,000 acre-feet per year, which includes evaporation losses from storage reservoirs and from the delivery systems.

In planning the location of a thermal nuclear power generating plant, EWEB proposed to establish a 2500 surface acre cooling reservoir which, during a normal growing season (mid-February through October), would supply condenser cooling water to approximately 150,000 agricultural acres (see Figure 1a). Water would be delivered to the downstream base of Fern Ridge reservoir and then divided between two major canals--one following the contour of the east side of the valley and ending at Albany, and one following the west side of the valley and terminating at Corvallis.

Two sites for power plant location were being considered--one at the confluence of the Willamette and McKenzie Rivers and the other at Poodle Creek, which flows into the Long Tom River, a tributary of the Willamette (see Appendix E for the technical rationale for early conceptual studies).

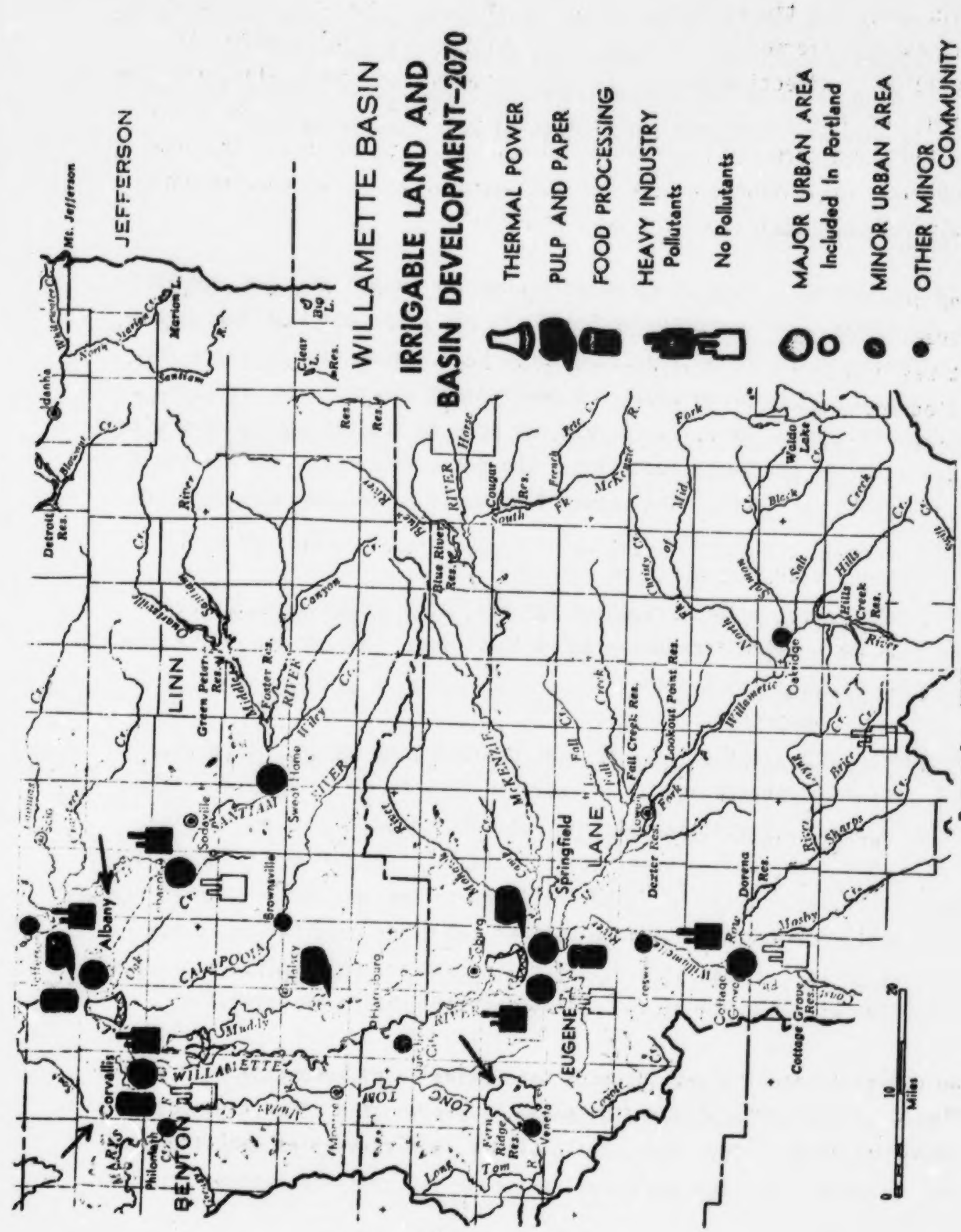
WILLAMETTE BASIN
IRRIGABLE LAND AND
BASIN DEVELOPMENT-2070
THERMAL POWER
PULP AND PAPER
FOOD PROCESSING
HEAVY INDUSTRY
Pollutants
No Pollutants
MAJOR URBAN AREA
Included In Portland
MINOR URBAN AREA
OTHER MINOR
COMMUNITY
JEFFERSON
LINN
LANE
BENTON
Mt. Jefferson
Detroit Res.
Idanha
Green Peter Res.
Foster Res.
Sodaville
Sweet Home
Albany
Corvallis
Philomath
Brownsville
Halsey
Harrisburg
Coburg
Junction City
Monroe
Springfield
EUGENE
Veneta
Fern Ridge Res.
Creswell
Cottage Grove
Cottage Grove Res.
Dorena Res.
Lowell
Dexter Res.
Lookout Point Res.
Fall Creek Res.
Blue River Res.
Cougar Res.
Hills Creek Res.
Oakridge
Waldo Lake
Clear L.
Big L.
SANTIAM
CALAPOOIA
WILLAMETTE
LONG TOM
McKENZIE
RIVER
Miles
0
10
20

Figure 1a. Willamette basin map

OBJECTIVES

This project's tie with the generation of nuclear power in the Upper Willamette afforded an exciting opportunity to materially assist in building an effective regional water management program. Along with the gathering of data, the Project was organized to demonstrate the ability of industry, farmers, engineers, Federal and State agencies, and educational institutions to work in close harmony in a new, complex agricultural undertaking for the benefit of all.

The original focus of this project was the isolation of any harmful aspects related to thermal water application in agriculture. In addition, it was proposed to demonstrate how heat energy in water could be dissipated while moderating, to the benefit of agriculture, an area's naturally occurring conditions of temperature and humidity. These benefit areas were to be explored:

- Increased yield and quality of crops through control of soil temperature and moisture content.
- Prevention of frost damage through heat dissipation from warm water application during frost conditions.
- Prevention of sunburn on soft fruits through control of humidity and atmospheric temperature.
- Lengthening of growing season for row crops and the possibility of double cropping.
- Introduction of new crops.
- Prevention of cold water shock.
- Fuller fruit and nutmeats through humidity control.
- The effect of thermal water irrigation on soil leaching and the run off of herbicides, fertilizers, and pesticides.

An undersoil-heating pipe network was installed on the project in early May of 1971 to demonstrate this mode of thermal water heat dissipation in agriculture. This facet of the project was correlated with the undersoil electric cable experiments of Dr. L. L. Boersma at Oregon State University. A 22 ft x 55 ft double-walled plastic greenhouse was erected over a portion of the soil heated area in 1971 to increase the output of data from the soil-heat demonstration.

As the project moved into its final period, emphasis was placed on gathering data that would be useful in quantifying the costs and benefits of thermal water agriculture and in assessing its associated role with conventional heat disposal techniques (i.e., cooling towers and ponds).

THE PROJECT'S ORGANIZATION

The project was to evolve into a cooperative venture. Overseeing the project were: the co-sponsors (EWEB and the Environmental Protection Agency) and the project manager (Vitro Engineering). Weyerhaeuser Company provided the thermal water source (water from the cooling condensers of the electrical generating plant for their Springfield mill). The demonstration took place on 170 acres under cultivation along the McKenzie River near Springfield; the seven farmers who owned this land agreed to use thermal water from the nearby (2 miles) Weyerhaeuser mill for irrigation, frost protection, and plant cooling.

THE IRRIGATION SYSTEM

The heated water from the Weyerhaeuser mill is discharged into the project's pumping pit (Figure 1). Water temperature at the pumping pit ranges from about 90 to 120°F. Two 1750-gpm and one 500-gpm pumps were used to deliver water to the project at about 80 to 90 psi. Water was pumped about 2 miles through a 16 in. diameter steel mainline (buried 30 in.) to the edge of the project's farms. Laterals fed individual farms. The mainline continued across the project's farms and was gradually reduced in size to 8 in. diameter.

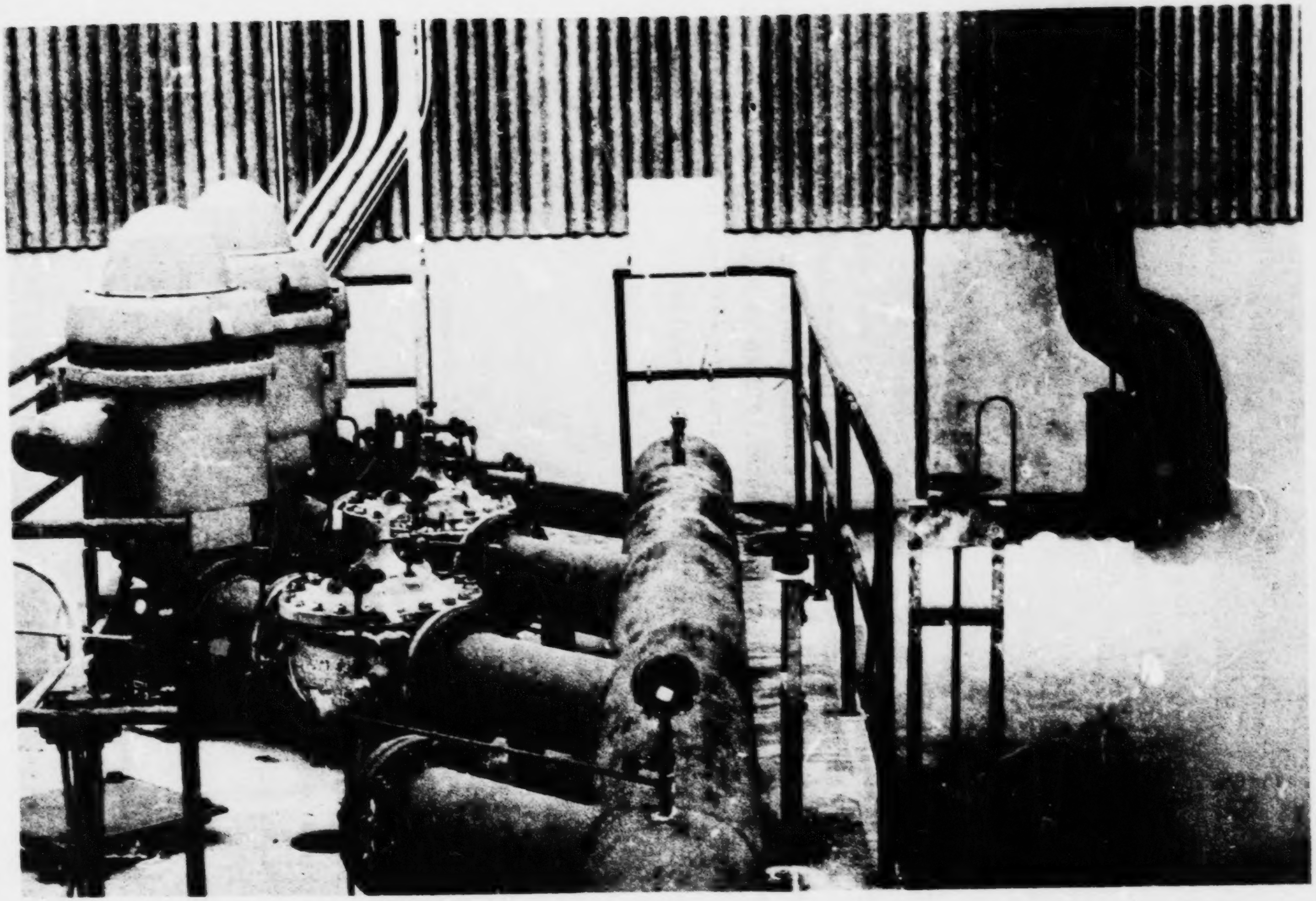

Figure 1: Weyerhaeuser Pumping Pit

At the end of the mainline, thermal water was sprayed into the air so that warm water was continuously moving through the system and immediately available at all project locations (Figure 2). The water that was sprayed into the air was cooled by evaporation to nearly ambient temperature and collected in a pool around the spray exhaust. The spray exhaust and pool were about 50 ft away and 10 ft above the summer level of the McKenzie River.

IRRIGATION SCHEDULING

Gypsum blocks (Delmhorst type) and tensiometers were installed throughout the project for monitoring soil moisture. The root depth zone was determined for each crop, as were percent allowable moisture depletion levels for each of the farm crops at various depths. These values were used as guides in determining when to irrigate. Each farm crop was considered separately, as much as possible, when irrigations were scheduled.

MONITORING EQUIPMENT

Wind Recording Systems

(1) 1-Weather Measure W101-Remote Recording Skyvane I

Specifications:

Starting speed	Approximately 1 mph
Range of measurements	0-65 mph
Accuracy	± 1 mph below 25 mph ± 5% above 25 mph
Sensor location	40 ft above ground

(2) 1-Weather Measure W123-Recording Wind System

Specifications:

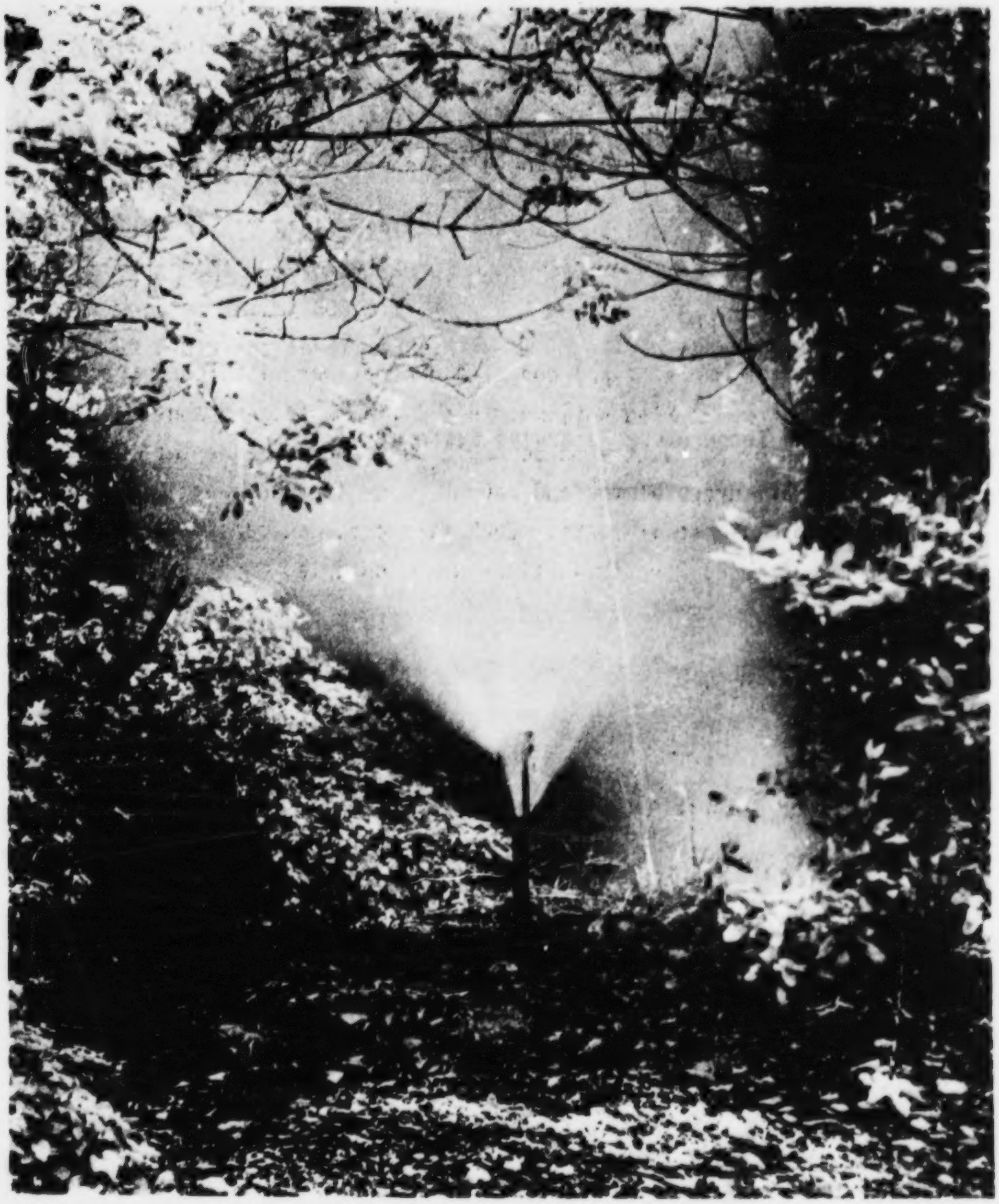

Figure 2: Thermal Water System Exhaust

Range of measurements	0-100 mph
Sensor location	12 ft above ground

Pressure Recording Systems

(3) 1-WM B211-Microbarograph
Specifications:

Sensor	14 cell, 2 1/2 in. dia. aneroid
Scales	27.9 to 31.0 in. of mercury
Accuracy	± 0.005 in. of mercury
Operating range	Sea level to 12,000 ft

Humidity and Temperature Recording Systems

(4) 5-WM H311 Hygrothermograph
Specifications:

Temperature	
Range	110°F, adjustable
Accuracy	± 1%
Humidity	
Range	0-100%
Sensor	Human hair bundle
Accuracy	± 1% between 20 and 80%
Sensitivity	Less than 1%

(5) 1 WM H361-6 Remote Dew-Point and Temperature System

Dew-point	
Sensing element	Lithium Chloride bobbin
Range	-40° to 120°F
Accuracy	± 2°F
Cavity temperature sensor	Platinum resistance bulb

Recorder

Accuracy	±0.5% of span
Sensitivity	0.1% of span
Ambient temperature limits	0° to 120°F

Total of 6 channels--1 for dew-point and 5 for ambient temperature

(6) 3 HM1 Sling Psychrometer

Thermometer range	-20 to +120°F

(7) T 641 Temperature Indicator/Alarm
Specifications:

Temperature range	10°F to 60°F and 60°F to 120°F; dual range
Alarm setpoint range	25°F to 35°F
Temperature resolution	1°F
Temperature probe	Precision thermistors in stainless steel case

(8) 1 WM T601 Remote Recording Thermograph
Specifications:

Calibration	-10 to 110°F
Accuracy	±0.2°C
Sensors	Mercury in plastic-covered capillaries

(9) 1 WM T601 Remote Recording Thermograph
Specifications:

Same as above except supplied with 1 probe

(10) 1 WM T611 Thermograph
Specifications:

Sensing element	Aged bimetallic strip
Accuracy	±1%
Range	110°F, adjustable

(11) 1 WM T622R-6 Temperature Recorder
Specifications:

Accuracy	±0.5% of full span
Sensitivity	0.1% of full span
Sensors	Platinum bulb 100 ohm
Temperature range	0 to 120°F

(12) 2 WM T622R-12 Temperature Recorder
Specifications:

Same as above except 12 points

(13) TM-1 Exposed Mercurial Thermometers

Range	-38 to +130°F

(14) TM-2 Minimum-Maximum Thermometers

Minimum range	-50 to +120°F
Maximum range	-38 to +130°F

(15) TM-2-LR Extra Minimum Thermometer

Evaporation Systems

(16) 1 WM E-801 Recording Evaporimeter
Specifications:

Calibration	0-10 min.
Accuracy	±1%
Sensor	Wetted filter paper 8.29 cm^2

Solar Radiation Recording Systems

(17) 1 WM-R401-Mechanical Pyranograph
Specifications:

Sensing Element	Black bimetallic strips
Calibration	gm-cal/cm^2/min
Full scale	Approximately 2.5 gm-cal/cm^2/min
Spectrum sensed	90% transmission, 0.36 to 2.0 micron wave lengths

(18) PRT-10 Barnes Engineering Co.
Infrared Thermometer

(19) PMS Instrument Co. Pressure Bomb

(20) Delta Temperature Unit

Precipitation System

(21) 1 P569 General Purpose Rain Gauge
(Forester Type)

SECTION II

THERMAL WATER CONDITIONS

THERMAL WATER TEMPERATURE

Temperature of thermal water from the Weyerhaeuser plant is first recorded at the project's pumping pit adjacent to the plant (Figure 1). Water temperature is next recorded at the inlet of the soil heat grid on the Bartholomew farm after the water has traveled about 2.7 miles through mainlines buried 30 in. beneath the soil surface.

Water temperature is recorded at the exit from the soil heat grid. The soil heat grid consists of twenty-five 2-1/2 in. diameter plastic pipes, each 470 ft long, connected to 8 in. diameter steel inlet and outlet manifolds. The grid is buried about 26 in. and is described in another section.

After the thermal water exits from the soil heat grid, it enters the mainline again and ultimately is exhausted into the air through a spray bleed valve (Figure 2). The water temporarily collects in a pool around the valve before filtering through several feet of gravel and soil into the McKenzie River. Water temperatures are recorded in the pool surrounding the spray exhaust (Figure 3).

Temperatures of heated soil in the open field and in the project greenhouse are partially dependent upon thermal water temperature. A summary of thermal water temperatures for 1972 and part of 1973 is shown in Figure 3. Relevant ambient air temperatures are shown in Figure 4.

McKenzie River water temperature tended to increase during mid-summer and decrease during the cooler months. This was also true of thermal water temperature.

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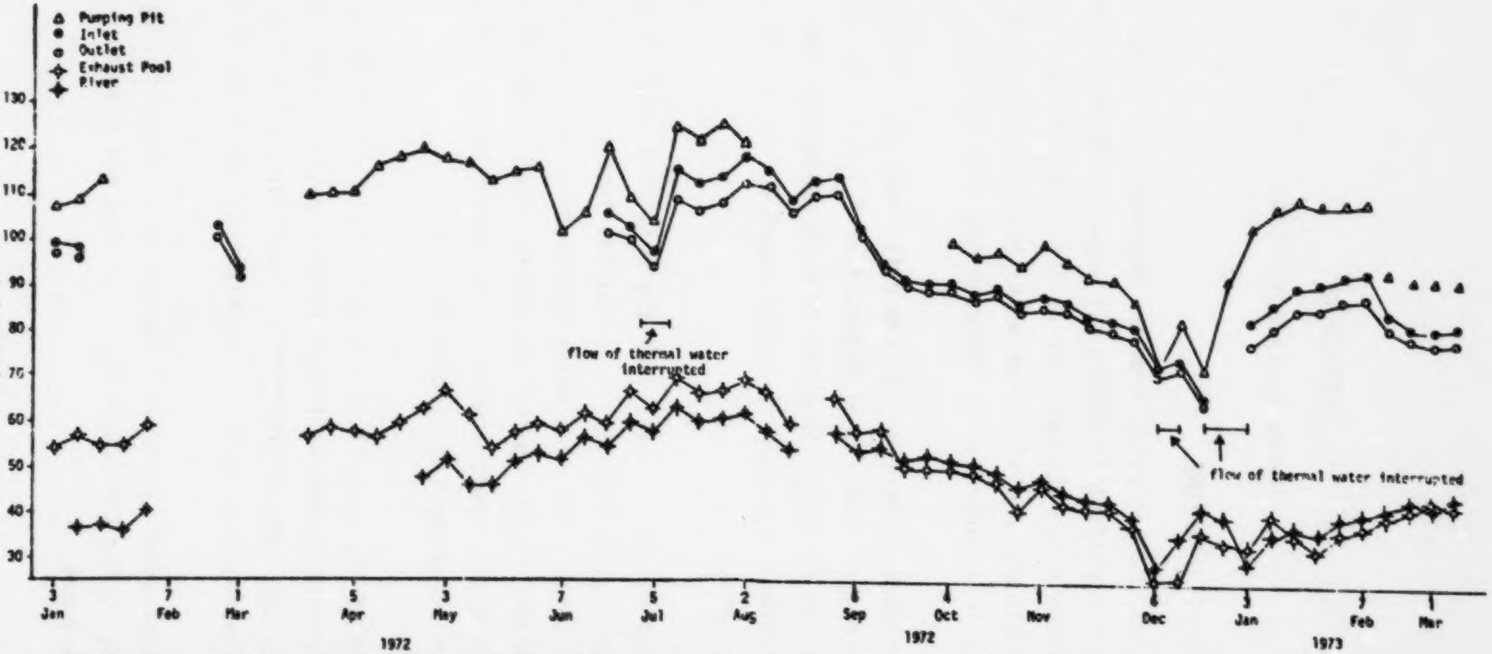

Figure 3. Weekly mean temperature of thermal water as it leaves cooling condenser of Weyerhaeuser's electrical generating plant (Pumping Pit), enters the soil heat grid (Inlet) about 2.7 miles from pump, exits from soil heat grid (Outlet), as it collects in pool surrounding spray exhaust (Exhaust Pool) before it filters through gravel back to the river and ambient river temperature (River).

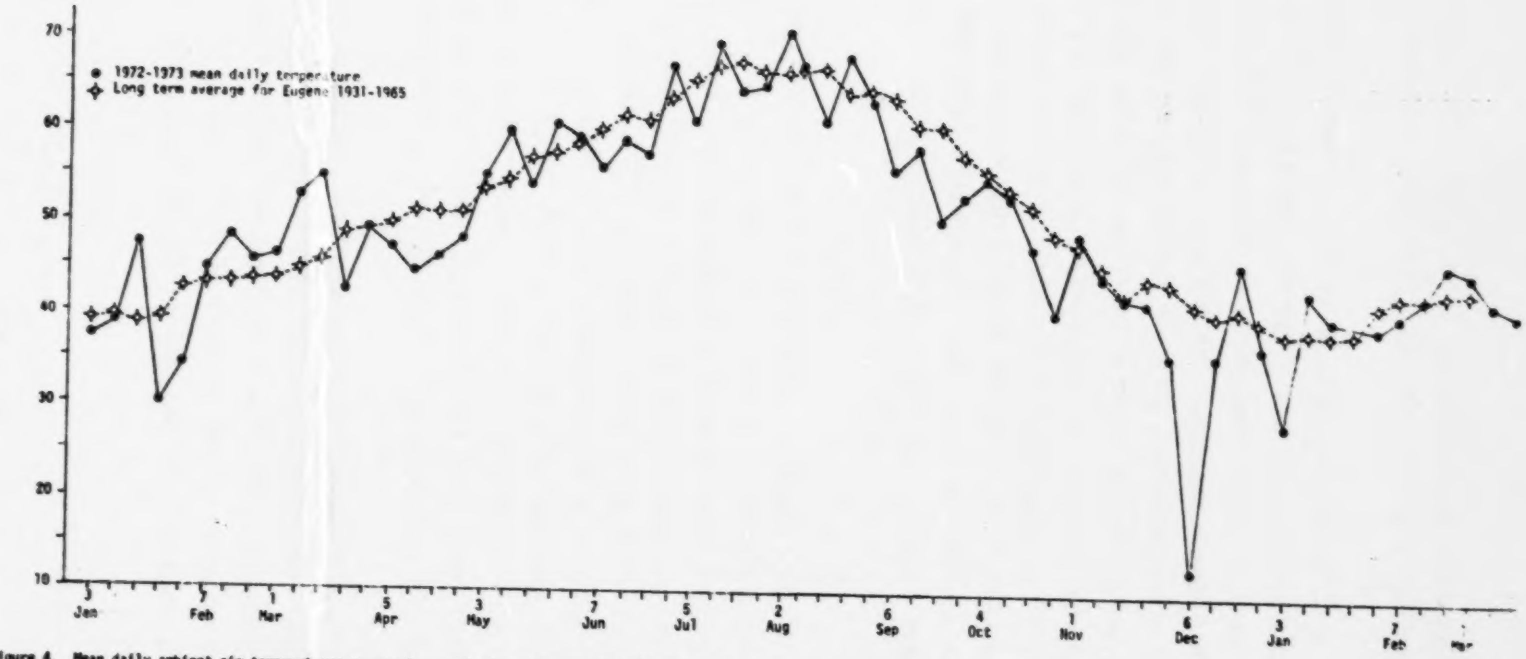

Figure 4. Mean daily ambient air temperatures averaged by weeks from January 1972 to March 1973 and long term weekly mean temperatures 1931-1965.

The pumping pit temperature recorder had to be removed for repairs during August 1972 and was not put back into operation until October.

During the first 4-1/2 months of 1972, there were greater temperature differences between exhaust pool and river than desirable. About mid-May, a new spray exhaust system that broke up the water into finer particles and promoted more evaporative cooling was installed. During June, July, and August, river water was slightly cooler than exhaust pool, but during the remainder of the year exhaust pool temperatures were slightly cooler than the river. One reason that exhaust pool temperatures showed up warmer than river is that the pool was shallow and the temperature sensor in the pool was found not to be fully shielded from the direct rays of the sun during part of the day. Thus, the average daily pool temperatures recorded were probably somewhat higher than the actual exhaust pool temperature.

Temperatures at the pumping pit ranged from a weekly average near 75°F during December to about 125°F in July 1972. River temperatures during the same period ranged from about 30°F in December to slightly above 60°F in July. The temperature drop of thermal water between the pumping pit and the soil heat grid inlet (about 2.7 miles) averaged 10.6°F for the period January 1972 through March 1973; temperature drop ranged from 2.8°F for the week beginning August 2, 1972, to 20.8°F for the week of January 10, 1973 (Figure 3). Thermal water temperatures recorded at sprinkler heads on the project were about the same as temperatures recorded at the soil heat grid inlet for any given period.

The temperature drop of thermal water between the pumping pit and the end of the line in the exhaust pool averaged 54.6°F for the period shown in Figure 3. The greatest difference in temperature between pumping pit and exhaust pool occurred during the week of January 24, 1973 (76.4°F difference); the least was for the week of December 20, 1972 (35.4°F difference).

SECTION III

FROST PROTECTION

INTRODUCTION

A solid set irrigation system that utilized thermal water with overtree sprinklers was placed in project orchards to protect fruit buds against frost damage. This technique of frost protection, but utilizing cool water, has been tested in nearly every major fruit district and has been proven practical.[3]

Sprinkler frost protection is possible because when water cools it gives up a fixed amount of heat per degree of temperature loss. One British thermal unit (Btu) of heat is given up per pound of water as it is reduced one degree Fahrenheit (F). However, when water is reduced to 32°F and freezes, it releases 144 Btu's per pound of water. Heat released during ice formation is called "latent heat of fusion." When a continuous film of water is applied to plants through sprinklers, the heat given off by actively freezing water keeps plant tissue at or above 31.5°F even though a layer of ice is formed on the plant. Ice is actually a good conductor and heat produced at the freezing surface is conducted readily to the buds.[4] The critical killing temperature of most plant tissue is below 31.5°F.

There are problems associated with frost protection by overtree sprinkling. The sprinkler system must be reliable and designed to irrigate the entire orchard at one time. If sprinkling is stopped at 32°F or below, plant tissue may be killed. Spur, twig, and limb breakage from heavy ice loads may occur under prolonged periods of water application. However, in apple and pear orchards in the Yakima Valley, limb breakage has not been a problem after the first year.[3] Proper pruning and additional tree supports help hold breakage to a minimum. Also, when large quantities of water will be required for protection in a particular area, it may not be possible to move heavy mobile spray equipment in and out of the orchard; fixed aerial spray equipment should be included in such a situation.

Although the sprinkler method is exacting, operation costs are lower than with other methods of frost protection; it is convenient, clean, and can be used for supplemental irrigation.

Project apple, cherry, peach, and pear orchards were located at the confluence of the Mohawk and McKenzie River Valleys. Cold air from the Cascade Mountains drains down these valleys in spring, and temperatures often fall below freezing during fruit bud swelling and blossoming and early fruit development. Project farmers estimated that frost partially damaged or destroyed fruit crops 2 or 3 years out of 5 before sprinkler frost protection systems were installed.

FROST PROTECTION OBJECTIVES

Objectives of the program were to show that thermal water could be used for frost protection to determine advantages or disadvantages in its use, and to determine if thermal water would modify orchard air temperatures.

PROCEDURE

Aluminum laterals were set on staggered spacings of 40 ft x 30 ft, 40 ft x 40 ft, and 40 ft x 50 ft, depending on spacing of trees. Full-circle sprinkler heads with a rotation rate of about 2 rpm were installed above tree height on 6, 10, or 15 ft risers. Steel fence posts were installed beside each riser for support. Depending upon sprinkler spacing, nozzle sizes of 3/32 or 7/64 in. were used to insure a uniform application rate of 0.12 in. per hr. The orchard area under sprinkler frost protection required about 2900 gal. per acre per hr or about 50 gal. per acre per minute. Pressure regulators set at 60 psi were installed at the top of each riser just below the sprinkler head. Pressure regulators at the nozzles were needed for uniform applications because mainline pressure varied from about 80 to 100 psi.

A variety of equipment was used to record orchard temperatures. Maximum and minimum temperature thermometers mounted on Townsend supports and hygrothermographs were placed inside standard U.S. Weather Bureau instrument shelters in each orchard. Temperatures were generally recorded 5 ft above soil surface. All project thermometers were calibrated with the U.S. Weather Bureau thermometers at Eugene's Mahlon Sweet Airport.

Exposed open-bulb minimum thermometers (Figure 5) were placed on Townsend supports attached to white posts in sprinkler protected orchards to record the equivalent temperature of exposed fruit buds during 1969, 1970, and 1971. An exposed thermometer in an orchard can be used to indicate the amount of protection when compared to a thermometer outside the sprinkler area.[5]

In addition to the above equipment, platinum resistance-bulb and thermistor temperature sensors connected to chart recorders were used to monitor dry bulb temperatures. The thermistors were used in a sensitive recording system where temperatures were recorded plus or minus a reference temperature (temperature difference or Delta-T recording system). Temperatures were recorded at 1, 5, 10, and 20 ft heights inside and outside sprinkler protected orchards during the 1972 and 1973 seasons.

Detailed information on critical bud temperatures of apples, cherries, peaches, and pears at different stages of blossom development was obtained from Washington State University publications in 1972.[6] [7] [8] [9] The information was given to the fruit growers on the project and was used to determine when frost protection was necessary.

A primary temperature alarm system was installed near the center of the project and a backup alarm was placed at the eastern edge. When the

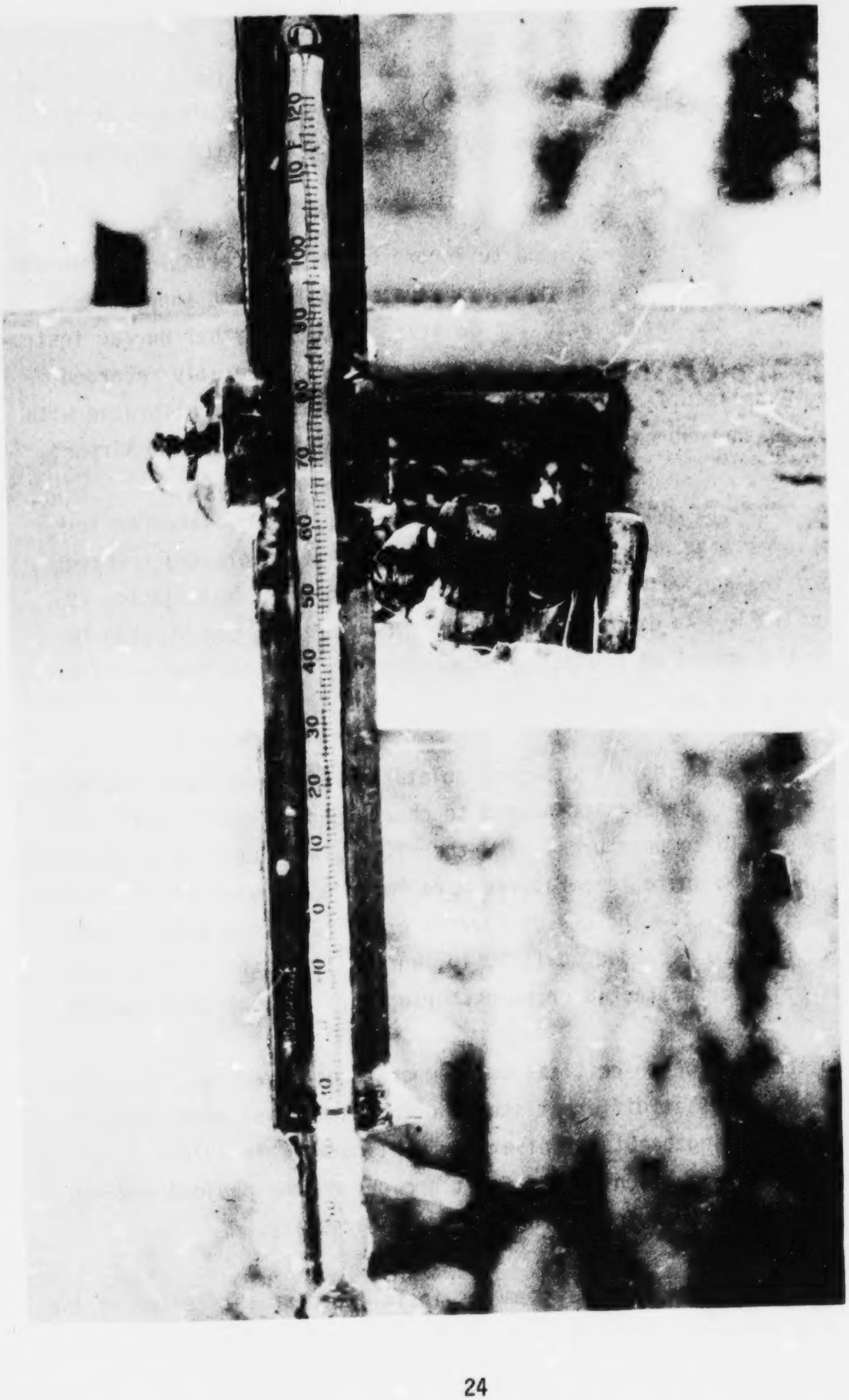
120
110 F
100
90
80
70
60
50
40
30
20
10
0
10

Figure 5: Exposed Open-Bulb Minimum Thermometer

temperature dropped to a selected level, an alarm was sounded by the primary system in each orchard grower's house alerting them to possible freeze damage. The backup system operated in only one grower's house. The systems were set to alarm about 2°F above critical bud temperature throughout the spring frost protection period after buds broke dormancy.

The effect of thermal water (applied through under-tree sprinklers) on air temperature at 1, 5, 10, and 20 ft in a sour cherry orchard was determined on March 23 and 24, 1973. Temperatures were measured with shielded thermistors connected to the Delta-T recording system. Thermal water was about 85°F at the sprinkler head, application rate was 0.22 in. per hr, and sprinklers were mounted on 18 in. risers for this study (Figures 6 through 9).

Row crops also were frost protected with thermal water. Eighteen-inch risers and an application rate of 0.12 in. per hr was used in 1969 and 1970. About 0.25 in. per hr was used in 1972. The degree of air temperature modification under the sprinklers was measured with shielded minimum thermometers in 1970. In 1972 the effect of thermal and cold-well water on temperatures 1, 5, 10, and 20 ft above the ground were measured with shielded thermistors connected to the Delta-T recorders. Irrigated blocks of row crops were 48 ft wide (east-west) and 218 ft long (north-south). Non-irrigated control, thermal, and cold water irrigated blocks were separated by 2 rows of sweet corn that were 7 to 9 ft tall. Temperatures were recorded near the middle of each irrigated block, and control temperatures were recorded in an open area west of the irrigated blocks. Thermal water was about 88°F and well water was about 56°F on nights row crops were protected. The row crops included tomatoes, peppers, snap beans, lima beans, beets, onions, cabbage, and cucumbers.

RESULTS

1969

Construction of the water delivery system was completed on March 21, 1969. At this time fruit buds were beginning to swell, and killing bud

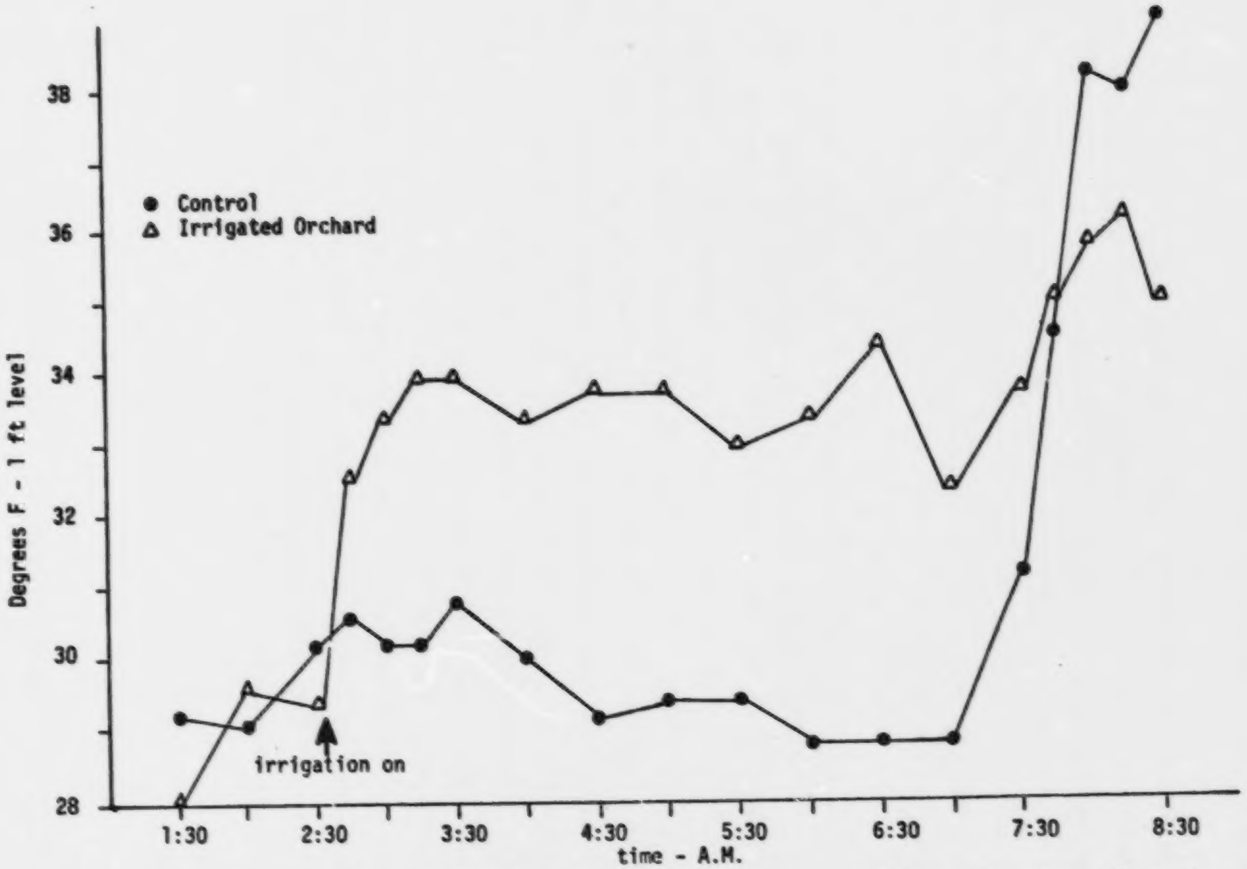

Figure 6. Influence of thermal water (85°F) applied through undertree sprinklers (at .22 in/hr) on air temperatures 1 foot above the ground on March 23, 1973. (Dew point was 24° to 26°F outside orchard.)

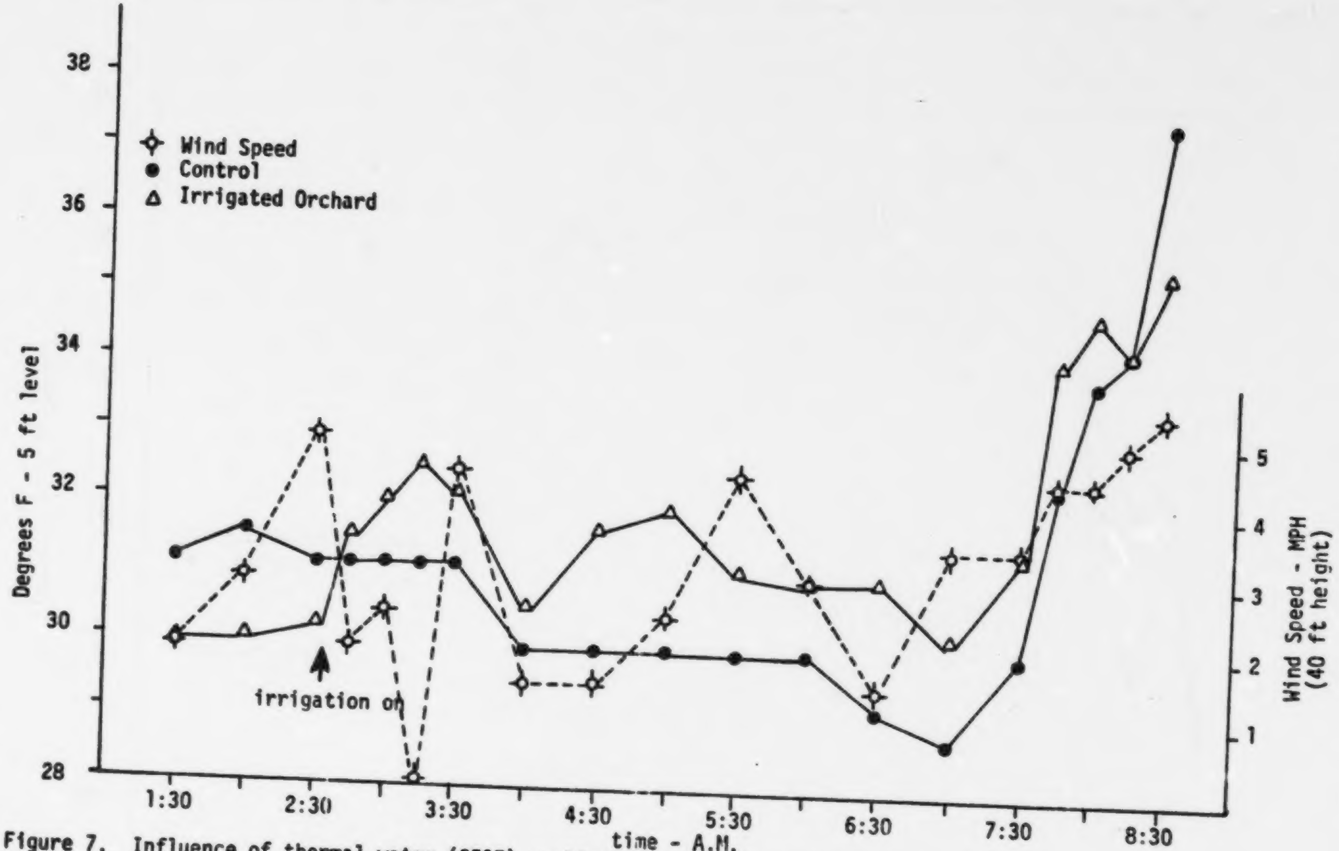

Figure 7. Influence of thermal water (85°F) applied through undertree sprinklers (at .22 in/hr) on air temperatures 5 feet above the ground on March 23, 1973. (Dew point was 24°F to 26°F outside orchard.)

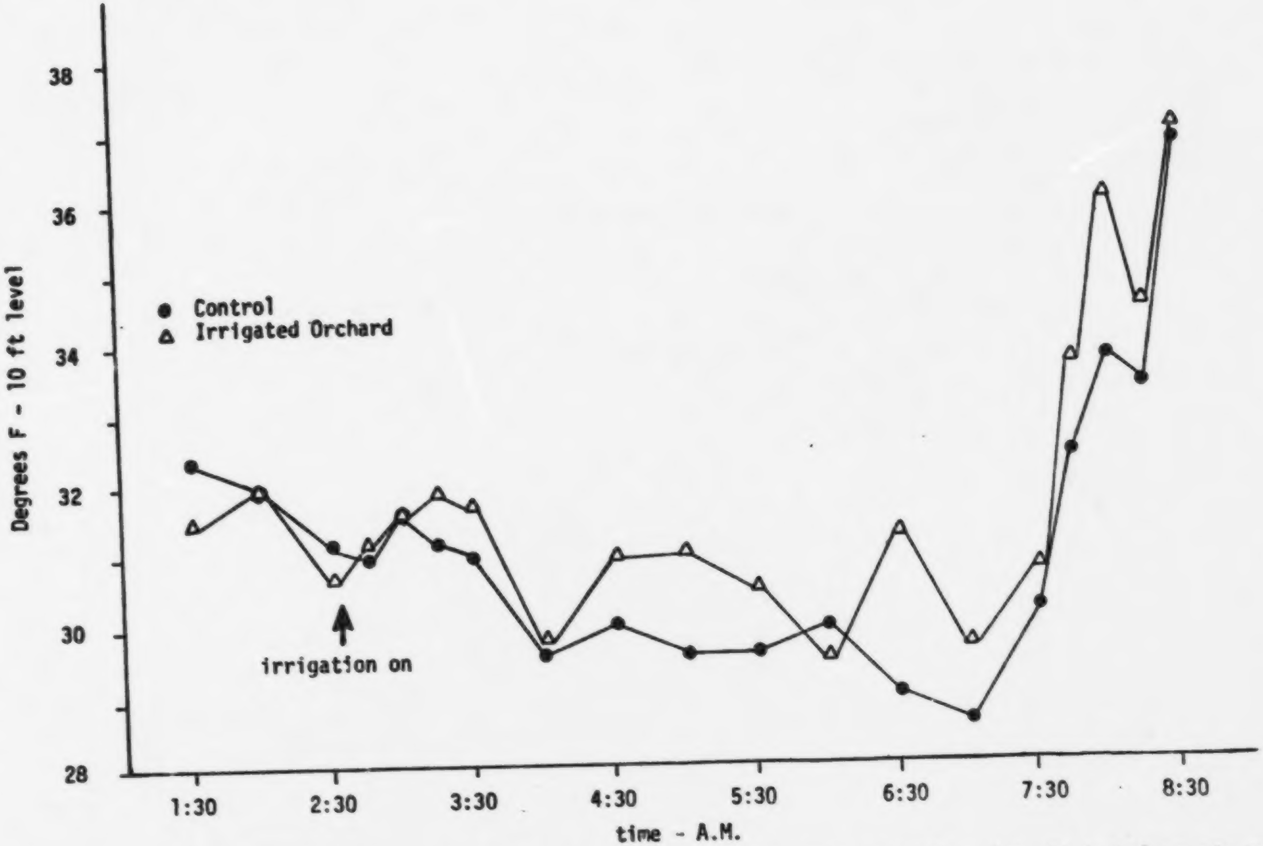

Figure 8. Influence of thermal water (85°F) applied through undertree sprinklers (at .22 in/hr) on air temperatures 10 feet above the ground on March 23, 1973. (Dew point was 24° to 26°F outside orchard).

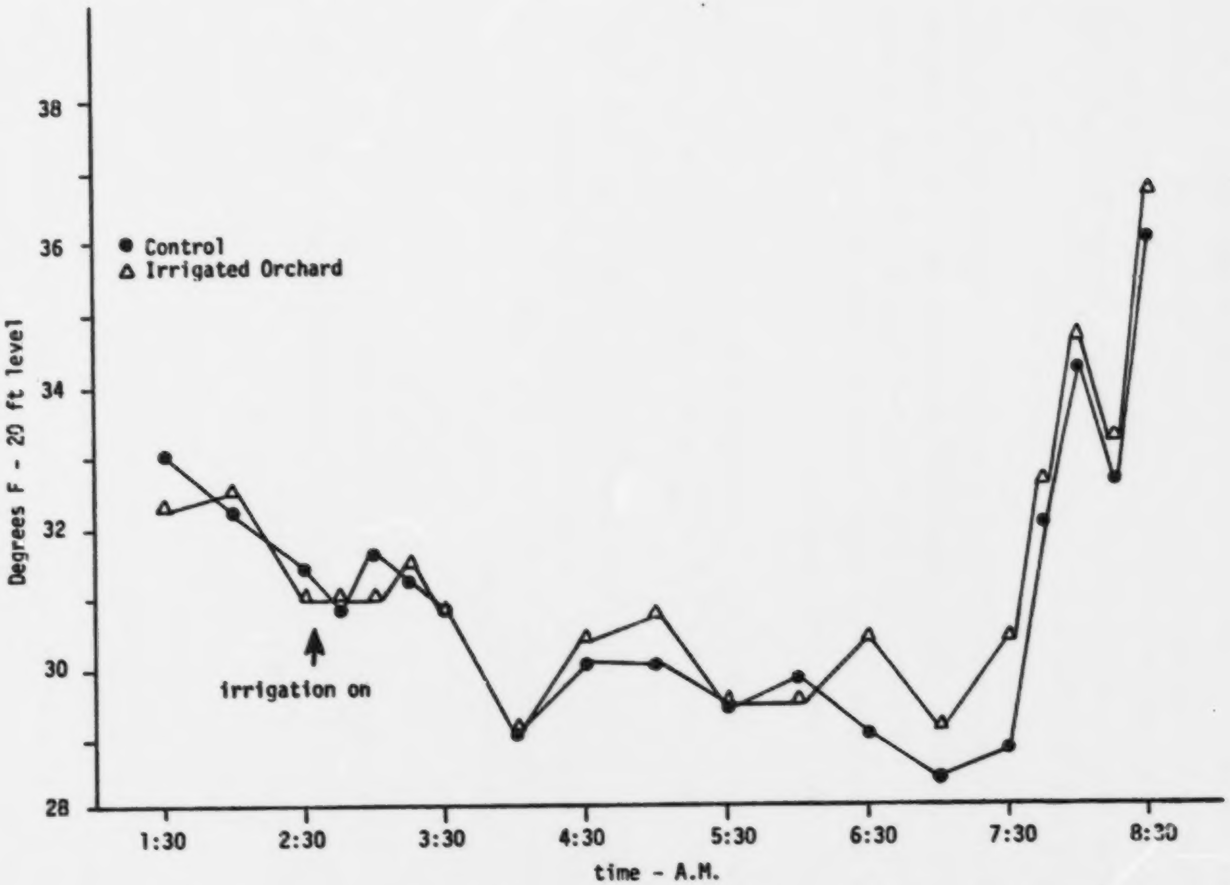

Figure 9. Influence of thermal water (85°F) applied through undertree sprinklers (at .22 in/hr) on air temperatures 20 feet above the ground on March 23, 1973. (Dew point was 24° to 26°F outside orchard.)

temperature was judged to be about 25°F. The sprinkler system was activated in all orchards on March 24, 1969, when the temperature dropped to 29°F; minimum temperature that night was 28°F. Although thermal water temperature was 110°F at the Weyerhaeuser pumping pit, water at the sprinkler head was only 70°F because not enough thermal water had been pumped through the system to warm soil surrounding the main and submains. Wind movement was out of the NNE at speeds up to 10 mph. Ice formed on buds and on those limbs of up to 2 in. diameter. Large limbs were dry or only had a very thin ice coat.

The following night, March 25, the temperature dropped to 30°F and sprinklers were activated. Water temperature was about 102°F at the pumping pit and 90°F at the sprinkler nozzles in the orchards. Minimum temperature was 30°F and wind movement was less than 2 mph. No ice was formed on buds or limbs under these conditions.

Considerably fewer cold nights than normal were recorded during April and May of 1969, and by mid-May night temperatures were well above freezing.

Fifty acres of orchard including pears, peaches, apples, sour cherries, and filberts were sprinkled with thermal water for frost protection in 1969. Several unprotected control fruit trees were not damaged by frost during the 1969 season. Temperatures apparently did not fall below critical levels.

Sprinkler-applied thermal water was used to protect 2 acres of strawberries from frost in 1969. The early blossoms were saved and a relatively early crop of berries resulted.

1970

An exceptionally warm two-week period during early February 1970 caused fruit buds to break dormancy about two weeks earlier than in 1969. A large quantity of water was applied to the orchards because of the early breaking of fruit bud dormancy and the subsequent cold nights. Fourteen to about 18 in. of water were used for frost protection in the various orchards (Table 1). The large amounts of applied water plus normal rainfall made a rigorous spraying and dusting program necessary.

Late February, March, and April were colder than normal. Minimum air temperature dropped below 28°F four times, and thermometers exposed to radiant-heat loss dropped below 28°F seven times. Sprinklers were activated 26 times in 1970 for frost control. Bud temperatures were held at 30.5°F to 31°F as recorded by exposed open bulb minimum thermometers. When sprinklers were activated during February and March, ice was formed even with water in excess of 100°F at the sprinkler head. During April temperatures dropped and recovered rapidly so that there were only short periods of freezing temperatures. No ice load developed on trees during frost protection in April.

A light fog was produced by thermal water applications on colder nights in February and March. When fog developed it was localized in the orchards and little fog drifted to adjacent residential areas. Sunlight always dissipated the fog soon after daybreak. Minimum orchard air temperatures ranged from 0 to 3°F warmer in frost-protected areas than in non-protected areas (Figure 10). Temperature differences were measured with minimum thermometers inside weather shelter.

No frost damage was found in any of the project orchards. There were, however, varying degrees of frost damaged fruit buds reported in Springfield-Eugene area orchards.[10] [11] Danger of freeze damage to filberts during spring did not appear to be great and no beneficial results were observed. Frost protection of filberts was discontinued after 1970.

In preparation for raising row crops under frost protection, low risers (18 in.) were installed and temperature was measured at about the 1-ft level. It was possible to hold the ambient air temperature several degrees above that of the unprotected areas. The thermal water from the low risers consistently increased the ambient temperature of the air from 2 to 5°F as measured with sheltered minimum thermometers (Figure 11).

Table 1. PRECIPITATION AND THERMAL WATER APPLIED FOR FROST CONTROL FROM FEBRUARY 15 TO MAY 31, 1970

Farm	Tree Crop	Precipitation, inches	Water Applied, inches	Total, inches
1	Peaches	6.2	14	20.2
4	Filberts	6.2	14	20.2
5	Pie Cherries	6.2	17.8	24.0
	Apples	6.2	17.8	24.0
	Pears	6.2	17.8	24.0
8	Apples	6.2	18.1	24.3
	Pears	6.2	18.1	24.3

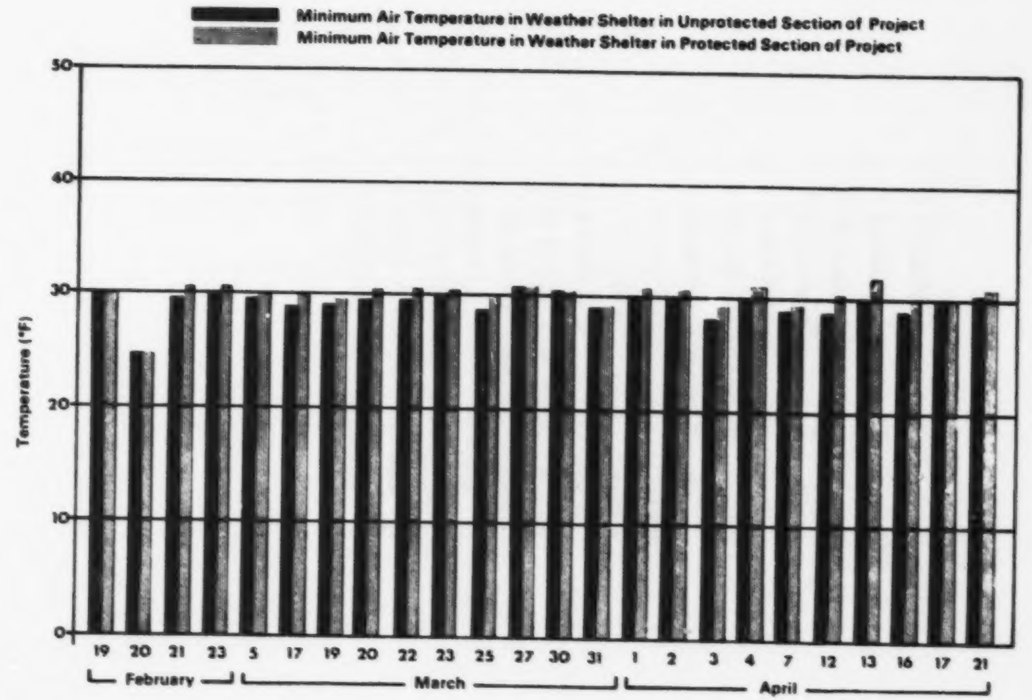

Figure 10: Air temperature modification at the 5 ft level under thermal water applied through sprinklers on 15 ft risers (1970).

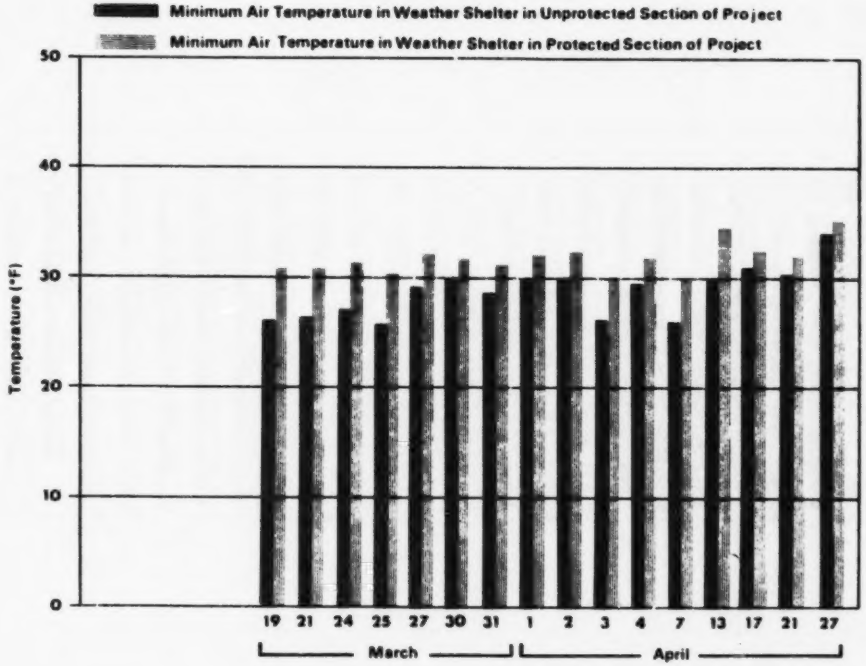

Figure 11: Air temperature modification at the 1 ft level under thermal water using 18 inch risers (1970).

1971

Pear fruit buds had swollen but were still tight, and apple and peach buds had just started to swell by late February. The first serious freeze of 1971 occurred on March 1 when the temperature dropped to a low of 18°F; temperature was below 20°F for 1-1/2 hr. Sprinklers were activated at 25°F (11:30 p.m., February 28) and remained on until 4:00 p.m., March 1, when air temperature reached 35°F. Very little ice load damage was found in peach and apple orchards in spite of an extremely heavy ice load (Figure 12). In the sour cherry orchard, 113 trees were damaged to some extent. Of those damaged, approximately 40 had to be replaced. Almost all of the damaged cherry trees were infested with heart rot, making them very susceptible to ice load damage. However, some ice load damage was noted on sound cherry trees.

On the following night (March 1-2), a low of 23°F was recorded. Sprinklers were turned on but no further ice load damage occurred. Temperatures dropped below freezing four more times during March, but did not drop low enough to damage fruit buds. The chance of freeze damage was lessened because buds developed slowly during spring of 1971.

Early severe frosts occurred in the fall of 1971 and a low of 28°F occurred October 17, 1971. The probability of 28°F occurring that early in the fall was only 4 percent at Eugene.[12] Walnuts were late in maturing and only about 5 percent of the nuts had fallen from the trees by October 17. The nuts that were on the ground were damaged by frost. For this reason, the thermal water sprinkler system was assembled under the walnut trees so that it could be used to protect fallen nuts from further freezes.

On November 5 and 6, the temperature dropped to 26°F and 23°F, respectively. According to U.S. Weather Service records, there is only about a 4 percent chance of temperatures this low occurring in early November.[12] These freezes severely damaged walnuts in the entire Willamette Valley.

Only about half of the project walnut crop had dropped from the trees before the November 5 and 6 frosts. The fallen nuts were protected from

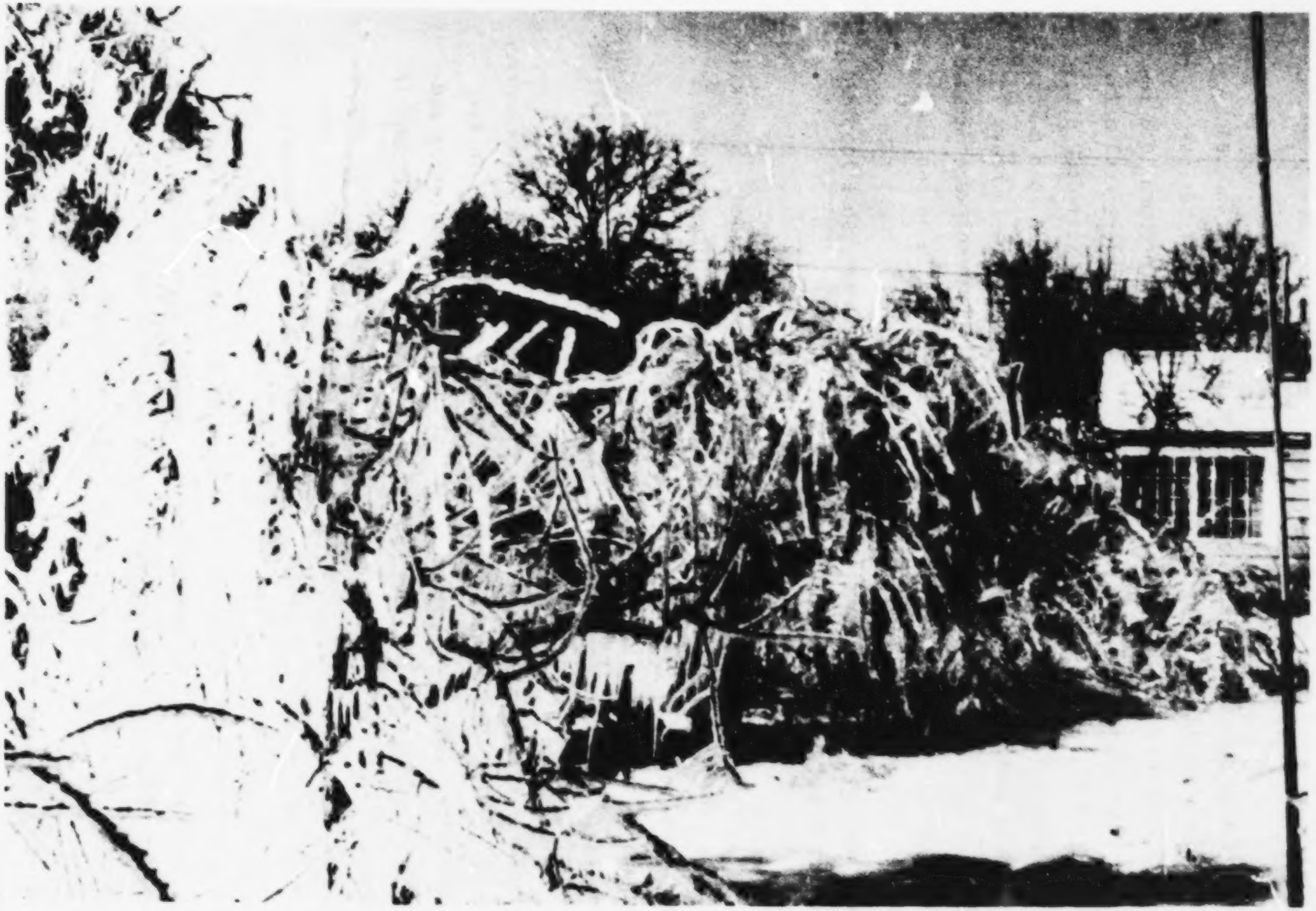

Figure 12: Ice Load in Peach and Apple Orchard

freeze damage with the thermal water sprinkler system. However, nuts remaining on the trees were severely damaged by the cold temperatures. Trees in the project walnut orchard were nearly 50 ft tall, and it was impractical to provide a sprinkler system capable of providing protection to nuts hanging in the trees.

Immediately after the November 5 and 6 freezes, the frost damaged nuts in the trees began to fall and resulted in a mixture of sound and damaged nuts on the ground. Because of the freeze damage, Hudson House, which buys approximately one-third of the state's walnut production, rejected a high percentage of walnuts grown in the Willamette Valley. Samples of walnuts from the project were subjected to crack-tests by Brunner Dryer, a nut drying firm. As high as 45 percent of the walnuts were found to be damaged and were rejected by the nut packer. However, the project grower was successful in marketing all of the commercially rejected nuts by selling them at his farm for a reduced price that reflected the average percent of damaged nuts.

1972

Temperatures below 32°F were recorded 10 times between March 7 and April 30, 1972. Sprinklers were activated on March 28, April 19, 22, and 30. Critical blossom bud temperatures for all project fruits were judged to be near 28°F by March 24 and throughout April, according to information in the literature.[6] [7] [8] [9]

The temperature dropped to 32°F at 11:50 p.m. on March 28, 1972, but remained around 31°F until early morning. Cold air moved out of the Mohawk Valley and the sprinklers were activated at 2:30 a.m., March 29, when the temperature fell to 29°F. The low for the night was 28°F. Sprinklers were turned off when the temperature reached about 35°F; this occurred between 8:00 and 8:30 a.m., March 29. Very little ice accumulated on the trees and no tree damage was observed.

During early April, 20-ft towers with shielded temperature sensors located at 5, 10, and 20 ft above the ground were placed in the sour cherry orchard and in adjacent open areas to monitor temperatures during periods of sprinkler frost protection. The towers located in the open areas served as non-irrigated checks. Temperatures were recorded on 6-channel recorders. Temperatures recorded with the above equipment during frost protection periods on April 19 are shown in Figures 13 through 15.

There was a rise in orchard temperature of about 1°F within the first 15 minutes of sprinkler operation. Temperatures at 5 ft and 10 ft were .5 to 1°F warmer, and 20 ft temperatures were 1 to 2.25°F warmer in protected orchards than in non-protected areas. The data shown for April 19, 1972, is representative of what occurred on other nights of frost protection. After the sun rose between 6:00 and 7:00 a.m., temperature build-up in the orchard was slower than in the non-irrigated check area.

In late summer 1972, cold and thermal water were used to protect a variety of vegetable crops from frost. The effect of cold and thermal water on vertical temperature gradients was recorded with the Delta-temperature recorders. The irrigated blocks were 48 ft wide (east-west) and 218 ft long (north-south). Non-irrigated, thermal, and cold water irrigated blocks were separated by two rows of sweet corn that were about 8 ft tall. Temperatures were recorded by shielded thermistors near the middle of each block at 1, 5, 10, and 20 ft above ground. Non-irrigated check block temperatures were recorded in an open area west of the irrigated blocks.

Thermal water temperature was 88 to 90°F and cold well water was 56°F at the sprinkler head. Sprinklers were on 18 in. risers and water application rate was about .25 in. per hr.

Sprinklers were turned on for frost protection on September 27 and October 24, 1972. On the night of September 27, the coldest air (31.5°F) was near the ground and the warmest air (36°F) recorded was at the 20 ft

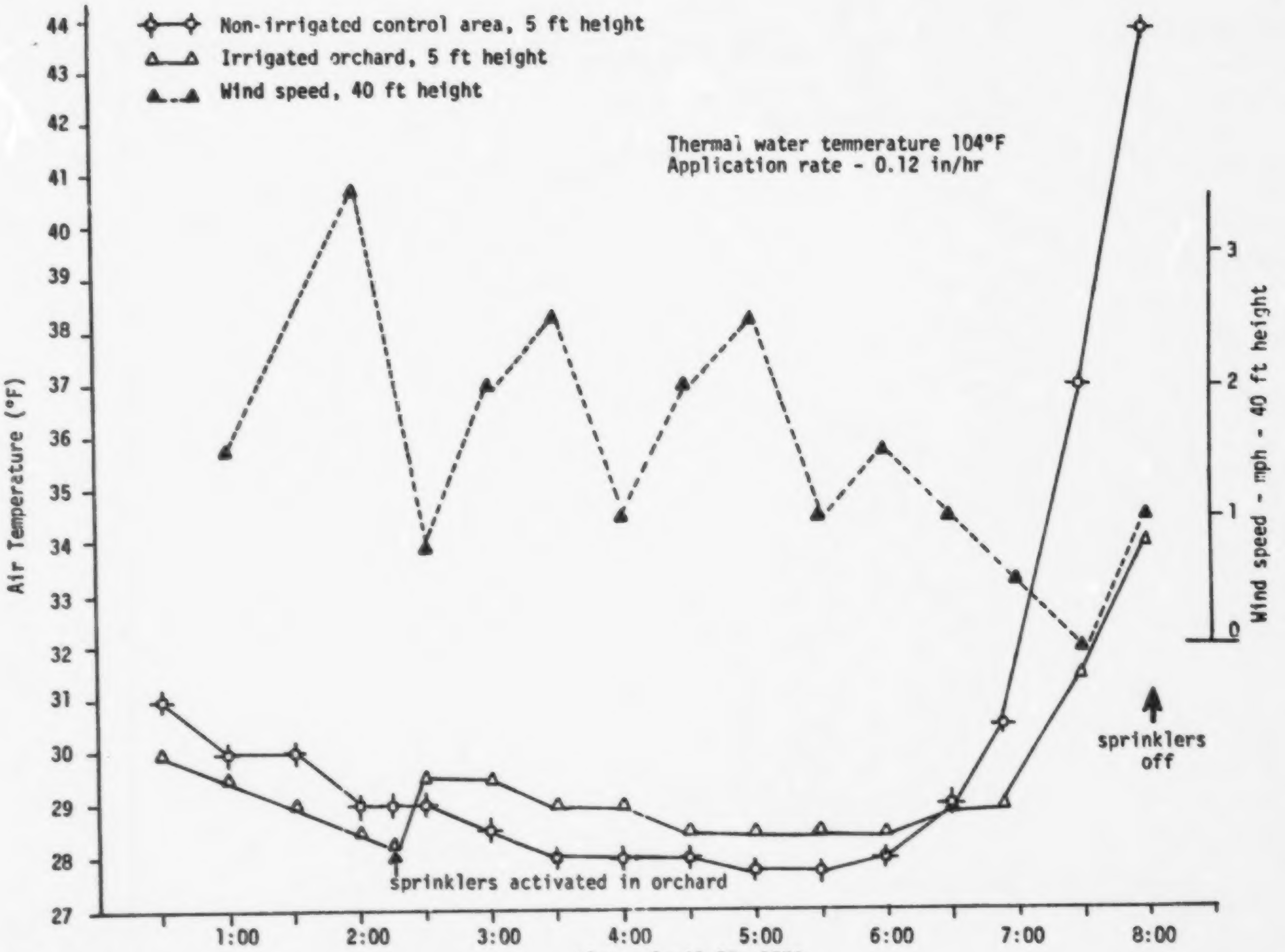

Figure 13. Air temperature at 5 ft height in a sour cherry orchard frost protected with overtree, sprinkler applied, thermal water and in an open area adjacent to orchard: wind speed recorded about 800 ft north of orchard.

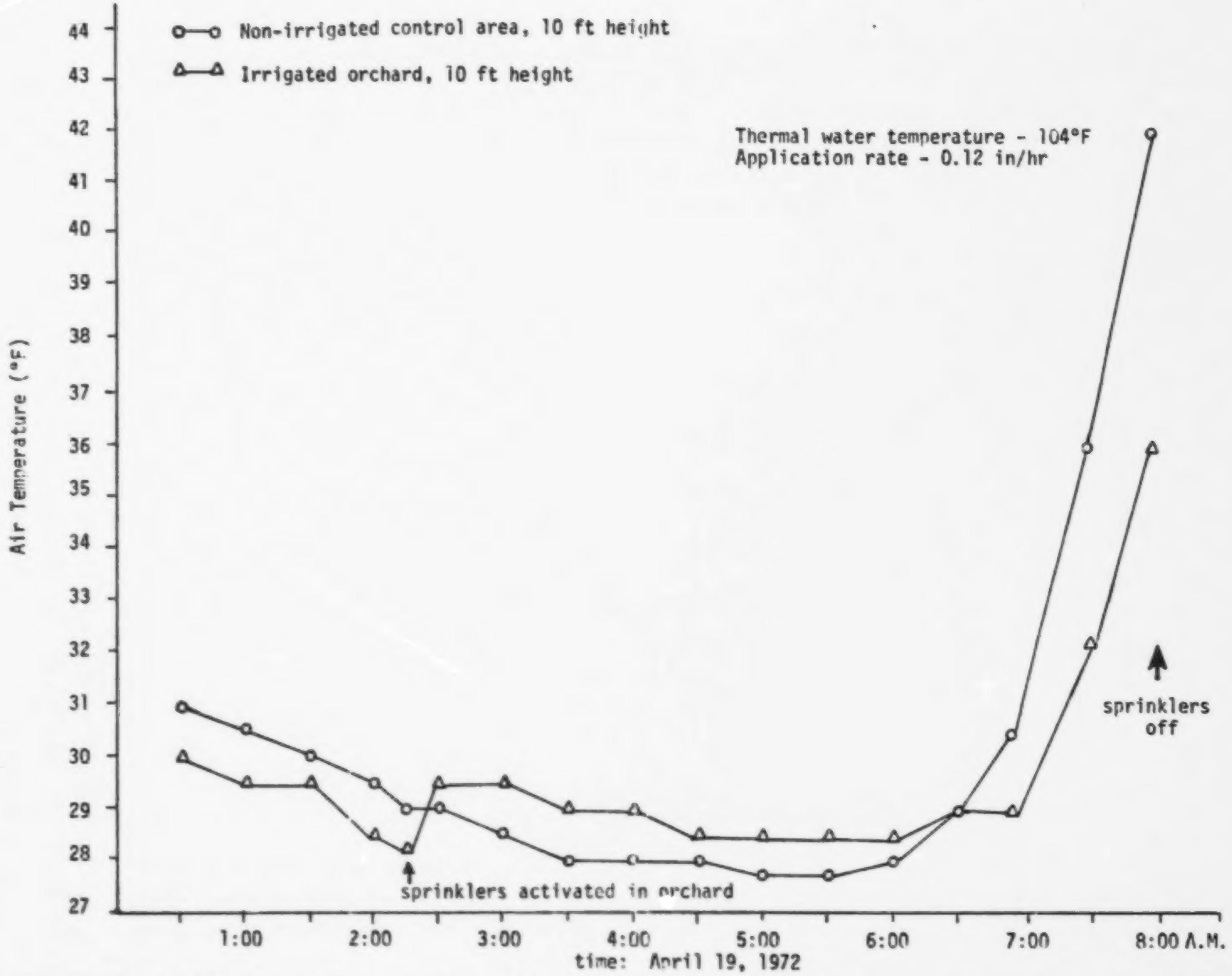

Figure 14. Air temperature at 10 ft height in a sour cherry orchard frost protected with overtree, sprinkler applied, thermal water and in an open area adjacent to orchard.

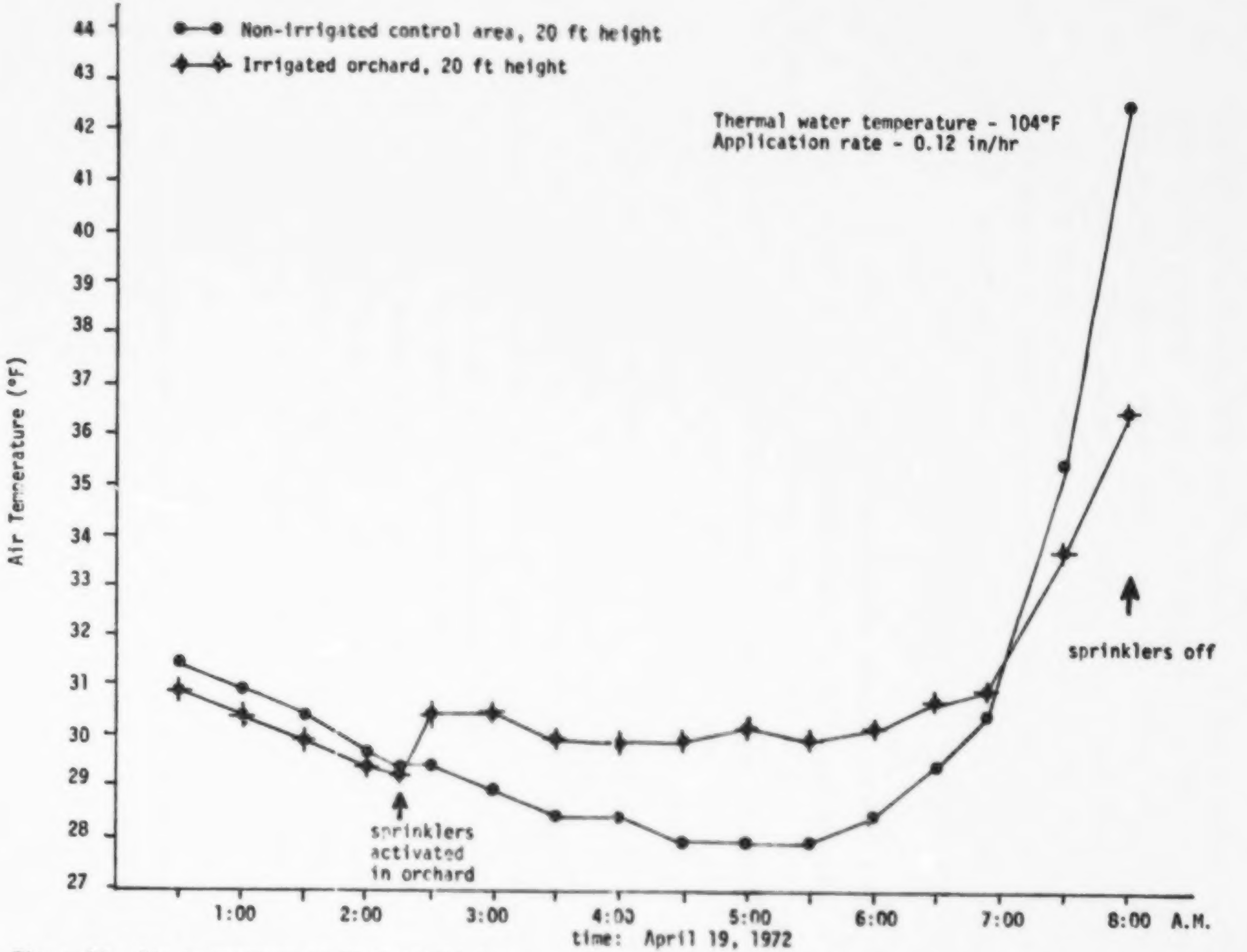

Figure 15. Air temperature at 20 ft height in a sour cherry orchard frost protected with overtree, sprinkler applied thermal water and in an open area adjacent to orchard.

level before the sprinklers were turned on. Air temperature throughout the 20 ft profile fluctuated fairly rapidly with changing air speeds. One-foot level temperatures hovered near 32°F before sprinklers were turned on at 5:15 a.m. (Figure 16). Generally, temperatures at all recorded heights in the cold and thermal water irrigated blocks were slightly cooler than in the control block before the irrigation was started. Cold and thermal water did not appear to modify temperature profiles much on the night of September 27 (Figures 16 through 19). However, non-irrigated crops were slightly damaged by frost. No frost damage was noted on sprinkled crops.

Sprinklers (18 in. risers) were turned on for frost protection of vegetable crops on September 27 and October 24, 1972. On the morning of September 27, the coldest air was near the ground (31.5°F) and the warmest air temperature recorded was at the 20 ft level (36°F) before the sprinklers were turned on. Air temperatures throughout the 20 ft profile fluctuated fairly rapidly with changing air speeds. One-foot level temperatures hovered near 32°F before sprinklers were turned on at 5:15 a.m. (Figure 16). Generally, temperatures at all recorded heights in the cold and thermal water irrigated blocks were slightly cooler than in the control block before the irrigation was started. Cold and thermal water did not appear to modify temperature profiles much on the morning of September 27 (Figures 16 through 19) or on October 24, 1972. Although air temperature was not modified much on these nights, non-protected plants were slightly damaged by frost while protected ones were not. The air temperature rise noted in thermal water protected areas with 18 in. risers in 1970 (Figure 11) were not detected in the fall of 1972.

Temperature profiles recorded on October 24, 1972, were similar to those recorded on September 27. Little apparent temperature profile modification was induced by sprinkling, but protected crops were not damaged by frost while non-protected crops were.

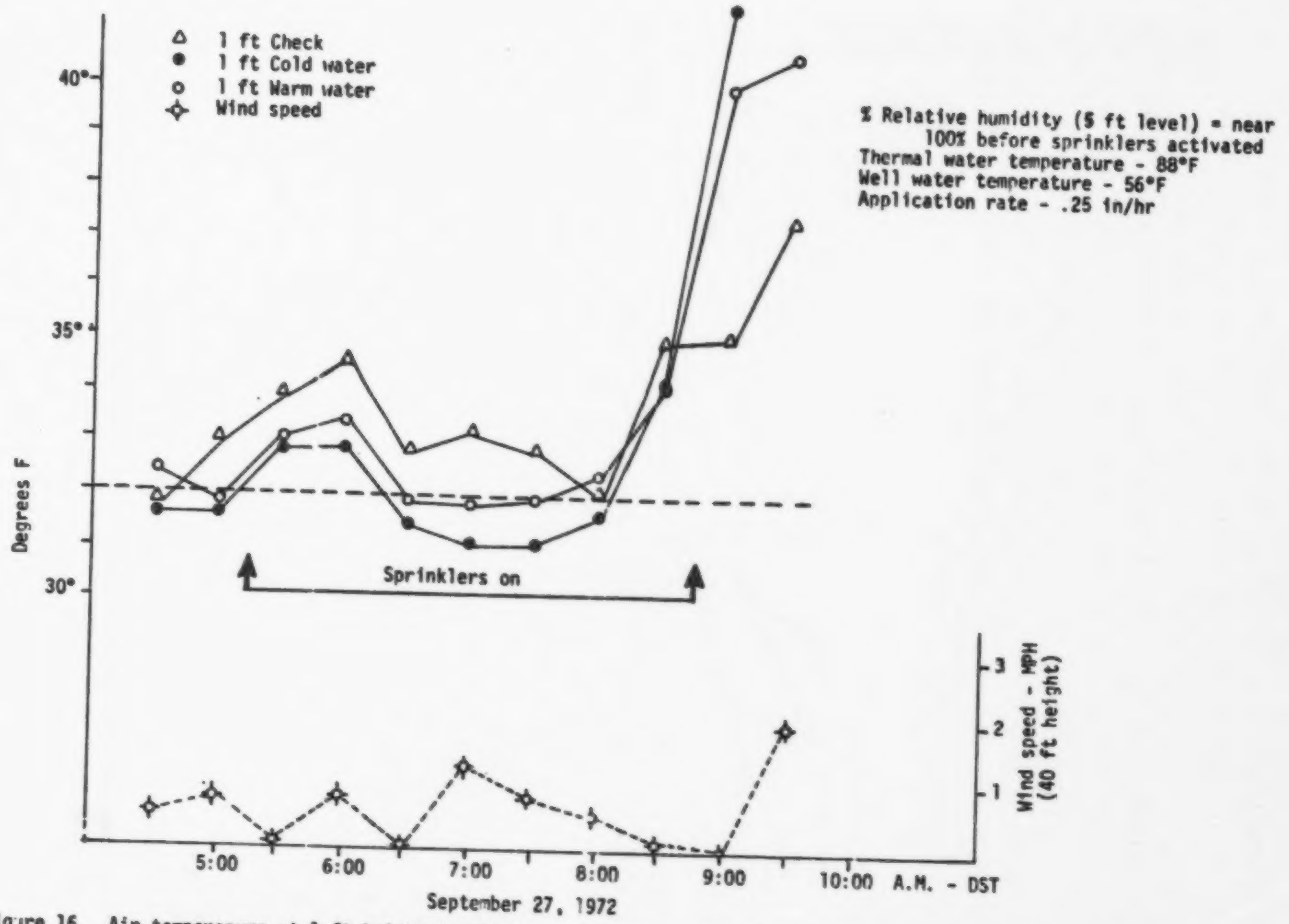

Figure 16. Air temperature at 1 ft height in blocks of vegetable crops that were frost protected with sprinkler applied thermal and cold water and in non-irrigated area: wind speed recorded about 1200 ft east of vegetable plots.

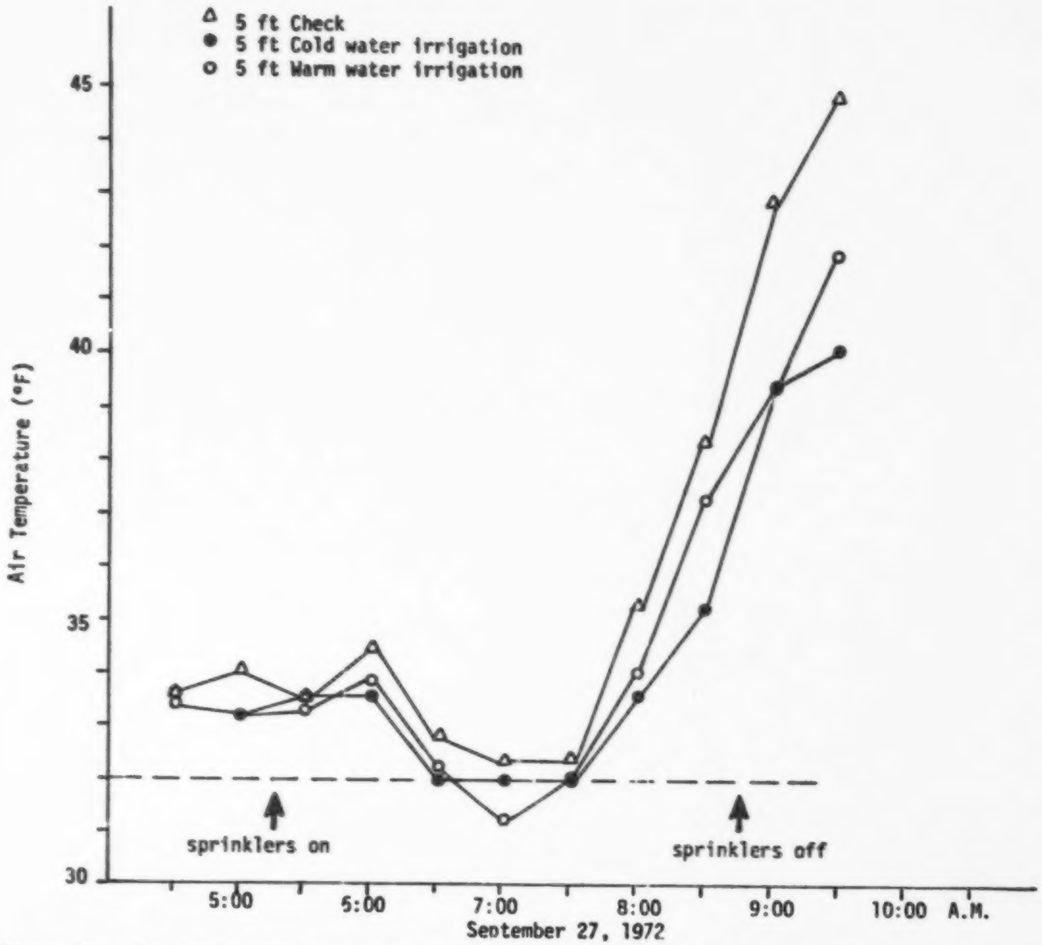

Figure 17. Air temperature at 5 ft height in blocks of vegetable crops that were frost protected with sprinkler applied thermal and cold water and in non-irrigated area: wind speed recorded about 1200 ft east of vegetable plots.

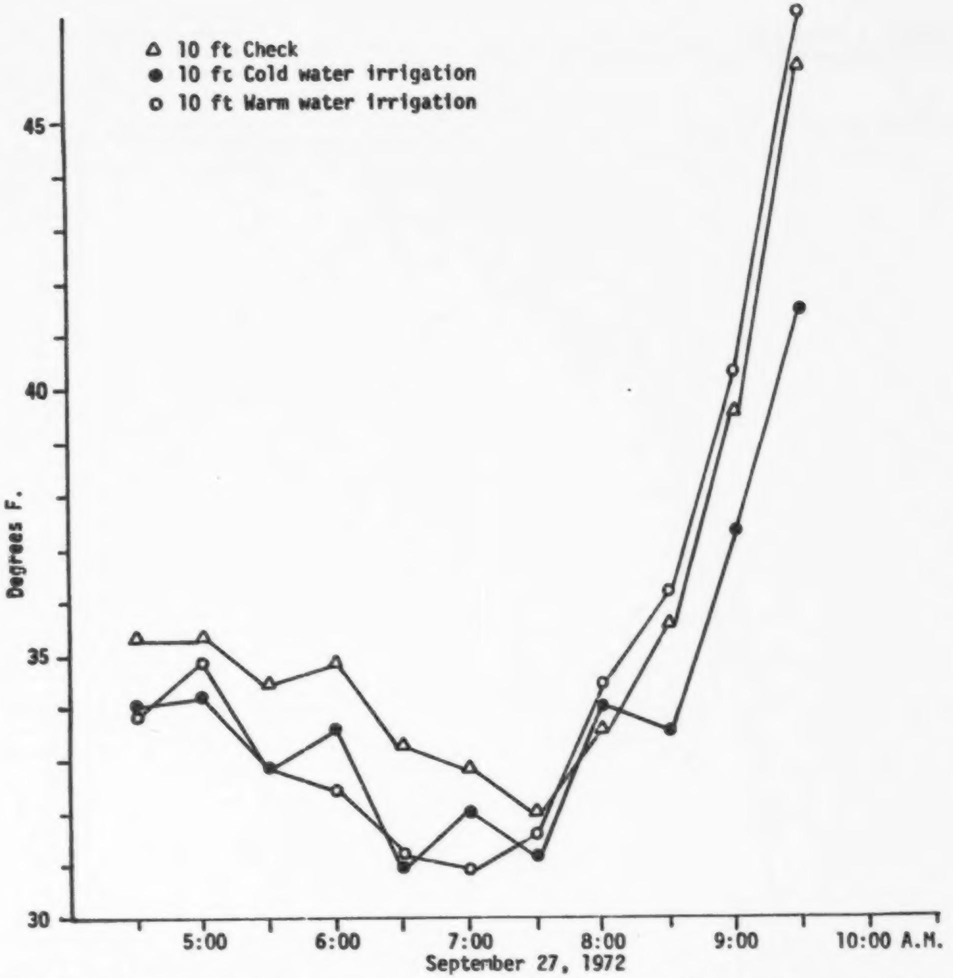

Figure 18. Air temperature at 10 ft height in blocks of vegetable crops that were frost protected with sprinkler applied thermal and cold water and in non-irrigated area: wind speed recorded about 1200 ft east of vegetable plots.

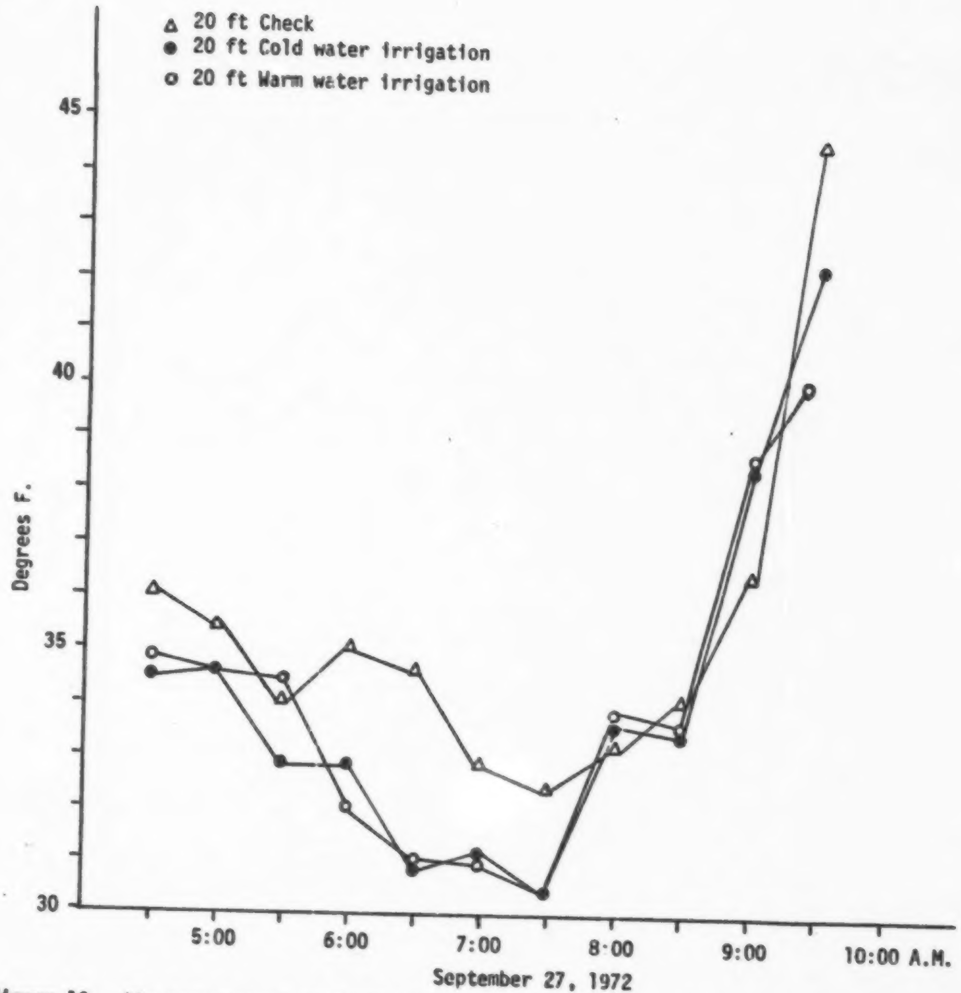

Figure 19. Air temperature at 20 ft height in blocks of vegetable crops that were frost protected with sprinkler applied thermal and cold water and in non-irrigated area: wind speed recorded about 1200 ft east of vegetable plots.

1973

Thermal water applied at 0.22 in. per hr through sprinklers on 18 in. risers increased air temperatures in a sour cherry orchard 3 to 5°F at the 1 ft level (Figure 6). At the 5 ft level, temperature in the sprinkled area was raised .5 to 2°F above the non-protected area (Figure 7); at the 10 ft and 20 ft height, a rise of 0 to 1.25°F was noted (Figures 8 and 9). Wind speed was recorded about 800 ft north of the sprinkled area and ranged from 0 to 5 mph during the time sprinklers were on (Figure 7). Dew points ranged from 24 to 26°F outside the sprinkled orchard area.

DISCUSSION

The temperature at which fruit buds are injured depends on their stage of development. Buds are most resistant to cold temperature damage during the winter when fully dormant. As the buds swell and expand into blossoms, they become less resistant to freeze damage and their critical temperature moves upward. For example, in March fruit buds may withstand 18°F but in late April they may not be able to withstand 28°F without injury. The resistance of buds to freezing can change from day to day in the spring and within any season; if frost should occur, buds are hardier following cold days than on mild or warm days.[13] The resistance of buds to freeze injury also can vary in the same tree because buds at different locations in the tree develop at different rates and have different exposure to the sun. Flowers or fruits exposed directly to the sky are usually colder than those that are sheltered. Fruit variety, tree vigor, humidity, wind speed, and duration of cold temperature all influence the degree of freeze damage and are important factors in determining whether or not a crop, particularly at full bloom and earlier, will survive.

Although critical bud temperature may be below 33°F, it has been suggested that irrigation for frost protection start when temperature of shielded thermometers drops to 34 to 33°F.[3] [14] This has been suggested because:

- It has been difficult to identify bud development stage and corresponding critical temperature.
- Evaporative cooling has been reported to reduce air temperature when water is initially turned on.[14] [15]
- Water in stand pipes may freeze and clog nozzles if the temperature drops below 32°F.

Washington State University's Extension Circulars 369, 370, 371, and 373 for apples, pears, cherries, and peaches have colored photographs of each bud development stage and their corresponding critical temperature.[6] [7] [8] [9] These publications became available in 1972 and made identification of specific bud development stages and critical bud temperature easier and served as a guide for sprinkler activation. Temperature profiles indicated that thermal water temperature apparently compensated for evaporative cooling effects, and no initial temperature depression was detected when sprinklers were first turned on (Figures 13 through 15). Because no temperature depression was noted, sprinklers were not turned on until the temperature dropped near critical bud temperature in 1972. Freezing of water in stand pipes and sprinkler heads was not a problem because the main and submain lines were buried. Water was not turned into the above ground lines and risers until it was needed for frost protection. By allowing the temperature to drop near the critical bud temperature before sprinklers were activated, much less water was applied than if sprinklers had been activated every time the temperature fell to about 33°F as suggested in the literature for cold water. For example, if sprinklers had been turned on at 32°F on April 19, 1972, they would have been on for several hours longer than they were (Figures 13, 14, and 15). Many more nights of frost protection in April 1972 would have been required if sprinklers had been turned on at about 33°F. The savings in water applications can be even greater in the early spring when critical bud temperature may be as low as 15 to 18°F. Fewer and lower water applications lessen the danger of ice load damage, reduce nutrient leaching from the soil, and reduce the times spray materials have to be reapplied.

It can be seen in Figures 13 through 15 that temperatures were allowed to drop to a point between 28.5 and 29.5°F before thermal water sprinklers were turned on. Although sprinklers were not activated until temperature was near the critical bud temperature (about 28°F during April 1972), there was no freeze damage and a depression of orchard temperature was not detected.

Sprinklers were activated 26 times in 1970, but dry bulb temperature dropped below 28°F only 4 times. Fruit buds will withstand about 28 to 30°F for a short period of time at their most sensitive stage of development.[6 7 8 9] Therefore, it is probable that trees were protected more often than necessary, especially early in the spring, because of lack of detailed bud temperature data. Perhaps the quantity and number of irrigations could have been reduced in 1970, and this could have aided general farm operations.

On March 1, 1971, ice loads damaged cherry trees. The temperature was below 20°F for 1-1/2 hr and a low of 18°F occurred. Cherries and apples had not broken dormancy by March 1 and may have withstood 18°F without great damage.[6] Pears and peaches had just broken dormancy by March 1 and may have withstood 18 to 20°F without extensive damage. As pointed out earlier, many factors would have determined the extent of freeze damage and a great risk would have been run if nothing had been done. If the critical bud information had been available, the sprinklers could have been activated somewhat later and the ice load damage might have been reduced.

In reviewing 1970 and 1971, it is only hypothetical what might have been. Problems encountered during 1970 and 1971 may have not been lessened even with the more recent information on critical bud temperatures and the indication that thermal water sprinklers do not have to be turned on until near critical bud temperature. However, further research is needed to confirm the observations reported here on handling thermal water for frost protection before it is used on large acreages.

In 1970 minimum temperatures were measured with minimum alcohol thermometers and the protected orchards were up to 3°F warmer than non-protected areas at the 5 ft level. Temperature profiles up to 20 ft were recorded with remote recording equipment in 1972 and 1973.

Temperatures at 5, 10, and 20 ft heights in the non-protected areas were nearly the same or slightly higher than temperatures in the orchard before thermal water sprinklers were activated on April 19 (Figures 13 through 15), 22, and 30, 1972. The orchard temperature sensors placed 20 ft above the ground were located above the tree canopy but underneath the highest part of the water arc from the sprinkler. As the water fell, it was cooled and the difference between temperatures inside and outside the irrigated orchard at 10 ft (Figure 14) and 5 ft (Figure 13) levels was less than at the 20 ft level (Figure 15).

When water is applied to several acres through a solid set irrigation system, the micro-climate within the irrigated block will be changed. Temperature and humidity will likely be raised in the zone below the level of the sprinklers. As much as 4°F increase in air temperature has been measured in a pear orchard with overtree sprinkling using cool water.[16] Thus, the temperature rise recorded in project orchards appears to be very reasonable.

On April 19, 1972, wind speed during the frost protection period ranged from 0 to 3.5 mph and averaged about 2 mph until 5:30 a.m. (Figure 13). Evaporative cooling is governed partly by wind speed. A vapor pressure deficit of 1 millibar (about 75% RH at 32°F) can cause a temperature depression of more than 1°F with a wind less than 0.5 mph; when the wind exceeds 2.5 mph, temperature depression is about 2.5°F.[15] The rate of wind movement during the April 19 frost protection probably lessened the rise of temperature in the overtree irrigated block. Wind speed on other nights of frost protection in 1972 averaged higher than on April 19 and rises in orchard temperatures were slightly less.

No fruit buds in thermal-water-protected orchards were damaged by 1972 spring freezes. A full crop of peaches was produced in the project orchards. Unprotected orchards in the Eugene-Springfield area produced no crop to a very light crop of peaches.

Although fruit buds were in no danger from 29°F on March 23 and 24, 1973, undertree sprinklers were turned on in a sour cherry orchard to determine the effect of thermal water applied through the sprinklers on air temperatures. Only temperature profiles for the morning of March 23 are shown (Figures 7, 8, and 9) but are representative of what occurred on March 24. The largest rise in temperature occurred in the sprinkled orchard at the 1 ft level (Figure 7). The greater the height of recorded temperature above the ground, the less temperature rise detected. Wind speed appeared to influence temperatures at recorded heights up to 10 ft. For example, as wind speed dropped at 6:30 a.m. (Figure 7), temperature at 5 and 10 ft levels increased by about 1.5°F. Wind speed may have reduced the influence of thermal water through evaporative cooling. Measurements made in an almond orchard in California showed that cold water applied through undertree sprinklers showed an advantage of 1 to 2°F.[17] The fact that there was almost no temperature modification at the 20 ft level and very little at the 10 ft level indicates that undertree sprinklers are not satisfactory for frost protection even when thermal water is used.

SECTION IV

THERMAL WATER IRRIGATION AND PLANT COOLING

THERMAL WATER IRRIGATION

Introduction

Although the 30 yr mean annual precipitation for the Eugene area is over 40 in., less than 2 in. of rain fall during the months of June, July, and August, which is the major portion of the growing season.[18] Thus for good crop production, irrigation is required in the Eugene/Springfield area.

Two major soil series are located within the project. Most of the soil is Newberg sandy loam with interspersed areas of Camas gravelly sandy loam.[19] The entire area is subject to flooding by the McKenzie River, which in the past has left sandy deposits throughout the soil profile. The water holding capacity of the soil is 1.25 in. per ft of soil with a permeability of about 2 in. per hr.[20] This is a light textured soil in which about 80% of its holding capacity is available water. Therefore, of the 1.25 in. of water held per foot, about 1 in. is available for crop use. The total available soil moisture was never allowed to be depleted below the critical level before the addition of irrigation water. The amount of water depletion allowed depended upon a number of conditions including the type of crop and stage of growth. The root depth of various crops directly influences the amount of soil moisture available to them. A shallow-rooted crop that relies upon only the top 1 ft of soil for its water will require less amounts but more frequent irrigations than a deep-rooted crop.

Theoretically, a water droplet passing through the air after leaving a sprinkler nozzle should approach wet-bulk temperature of the air.[21]

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The wet-bulb temperature is defined as the temperature that the air assumes when water at current temperature is introduced gradually and evaporated adiabatically at constant pressure until the air is saturated. Temperature of sprinkler spray water is changed by evaporation, conduction, and to some extent by radiation of heat to or from the air. When initial water temperature is higher than air temperature, the droplet temperature will decrease as it passes through the air by evaporative cooling and by loss of heat through molecular collisions. After cooling to air temperature, droplets continue to cool by evaporation to the wet-bulb temperature, if the droplets remain in the air long enough. The actual rate of cooling depends on the difference between the wet-bulb and dry-bulb temperatures of the air, the volume and shape of the droplet, and the velocity of the droplet relative to the air through which it is passing. If the initial temperature of water leaving a sprinkler is below wet-bulb temperature, the droplet will be warmed as it passes through the air by molecular collision; if it is in the air long enough, the droplets could reach wet-bulb temperature.

Studies by Pair[22] indicated that hot water could be used for sprinkler irrigation of crops without much concern for the effects of high water temperatures. His tests demonstrated that water temperature increased as much as 15°F when it was initially below wet-bulb temperature, and cooled as much as 135°F when it was intially above wet-bulb temperature. According to Pair, water temperature varied little with distance from the sprinkler. The smaller drops traveled a shorter distance, but because of size their temperatures approached wet-bulb equilibrium more rapidly. The larger drops traveled a greater distance and thus had more opportunity to approach wet-bulb temperature.

It was determined that thermal water cooled about 2°F per ft distance it traveled from the sprinkler nozzle during periods of low relative humidity in tests conducted on the project in May and July 1969 (Figures 20 and 21). This confirms the findings of Pair that, during

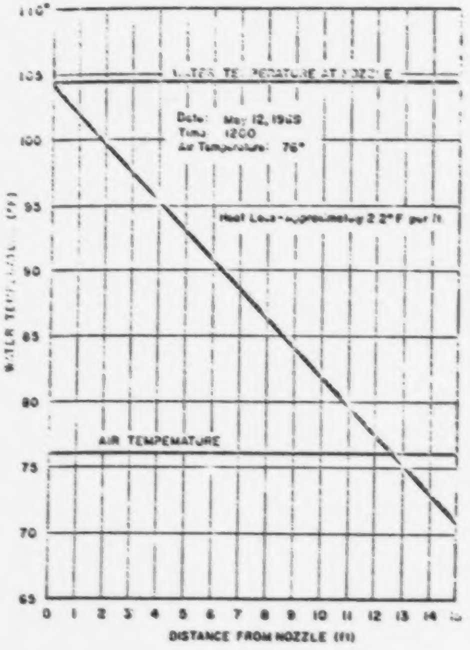


Figure 20: Water Temperature Drop Through Sprinkler Application (5-12-69)

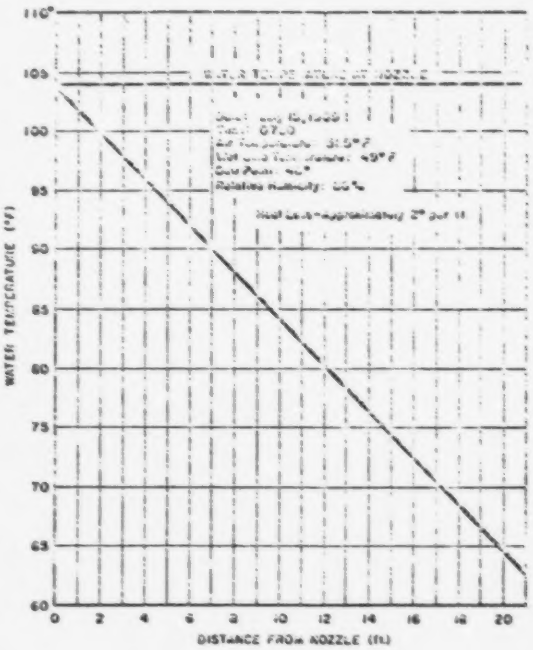


Figure 21: Water Temperature Drop Through Sprinkler Application (7-15-69)

periods of high ambient air temperatures, water in excess of 100°F at the sprinkler nozzle may be below ambient air temperature by the time it reaches the plants.

Thermal irrigation water was not available from May 6 to July 19, 1971, because the Weyerhaeuser plant, which supplies the thermal water, was not in operation. During this period, relatively cool water from the McKenzie River was used for irrigation (Figure 22). By the time thermal water was available, pole beans were within one week and sweet corn within three weeks of harvest. Because thermal water was not available for much of the 1971 growing season, it was not possible to determine the effects of it on crop production. However, studies were conducted to determine the effect of thermal water on soil temperature when applied by rill and flood irrigation late in the growing season.

Procedure

Each farm crop was considered separately, as much as possible, when scheduling irrigations. The critical root-depth zone was determined for each crop, and it varied from the deep root zone of the walnut tree to the shallow zone of snap beans. Gypsum blocks and tensiometers were installed throughout the project for monitoring soil moisture and the information was used for irrigation scheduling. The critical depth and percent allowable moisture depletion level for most of the crops are listed in Table 2.

On July 28, 1971, the effects of thermal and cool water furrow irrigation on soil temperatures were observed in a soybean plot. Furrows were about 2 in. deep and 10 in. to the sides of the plant row. Temperature sensors were placed at 6 and 12 in. depths beneath the bottom of the furrow and soil surface halfway between the furrows (Figure 23). Temperature sensors were placed at the same depths in a non-irrigated check plot. The furrow irrigation plots were underlaid with soil heating pipes that were at a 2 ft depth (see Soil Heating Study for description of soil heating system).

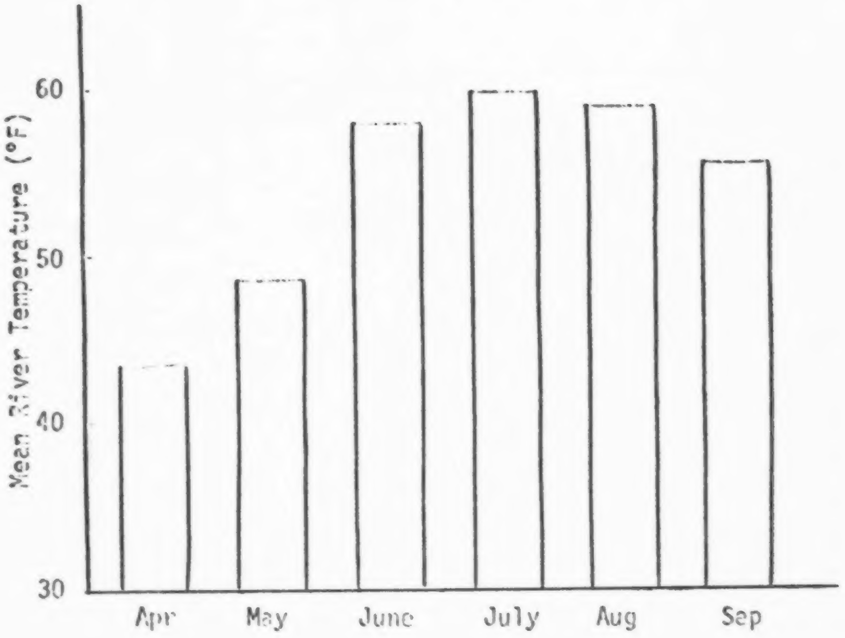


Figure 22: Mean monthly temperature of McKenzie River in 1971.

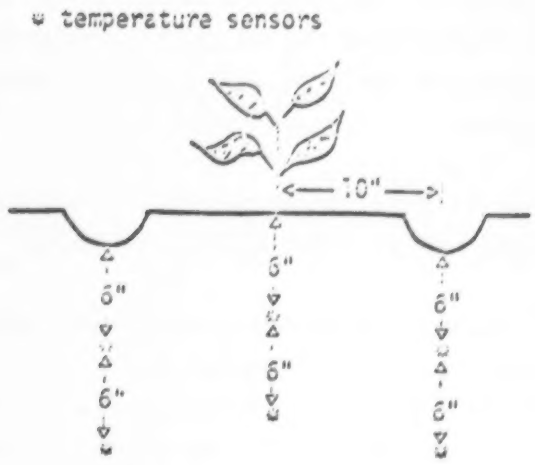
Table 2. CRITICAL DEPTHS AND ALLOWABLE SOIL MOISTURE DEPLETION FOR VARIOUS CROPS

Gypsum Blocks

Crop	Instrument Critical Depth, ft	Minimum Allowable Meter Reading, mmohs	Maximum Allowable Available Soil Moisture Depletion At Critical Depth, %
Peaches	1.5	170	50
Apples	1.5	170	50
Cherries	1.5	170	50
Pears	1.5	170	50
Filberts	1.5	170	50
Walnuts	1.5	170	50
Tomatoes	1.0	170	50

Tensiometers

Crop	Instrument Critical Depth, ft	Maximum Allowable Instrument Reading, atmospheres	Maximum Allowable Available Soil Moisture Depletion At Critical Depth, %
Potatoes	0.5	0.3	40
Beans	1.0	0.4	50
Corn	1.0	0.5	50



• temperature sensors
10"
6"
6"
6"
6"
6"
6"

Figure 23: Temperature sensor placement.

Thermal water at 88°F and well water at 60°F were applied to adjacent plots at a rate of about 10 gpm starting at 10:45 a.m. Soil moisture in the sandy loam soil was about 60 percent of field capacity when water applications started.

On August 3, 1971, mature tomato plants were flood irrigated with 108°F water for one hour at the rate of about 2 gpm (equivalent of about 2.7 acre feet water applied). Soil temperatures were monitored at 6, 9, and 12 in. depths below the plants. The soil temperature at the 6 in. depth increased 31°F but only increased 10°F at the 12 in. depth (Figure 24). Equilibrium temperatures had not been attained after one hour of flooding, but the trial was terminated because excessive water had been applied.

The effects of thermal and cold water sprinkler irrigation on plant growth were compared in more detailed studies in 1972.

During June 1972, a study was initiated to compare trunk growth made by filbert nut trees on plots irrigated with cold well water, thermal water, and on non-irrigated plots. The average tree age was 10 to 12 yrs. Tree spacing was 20 x 20 ft. The cold water and non-irrigated block contained 30 trees each; the thermal water block contained 48 trees.

Temperature of well water used for irrigation was about 50 to 55°F. Thermal water temperature at the header averaged about 100 to 110°F, about the same as temperatures recorded at the inlet of the soil heat grid. The thermal and cold water blocks were irrigated at the same time and the same amount of water was applied to each block. The following is a summary of filbert irrigation applications: July 13, .70 in. water; July 19 and 20, 2.4 in. water; and August 8, 3.5 in. water (Table 3).

Trunk growth was measured with the Verner-type dendrometer. This instrument has been used to measure growth of fruit trees and various

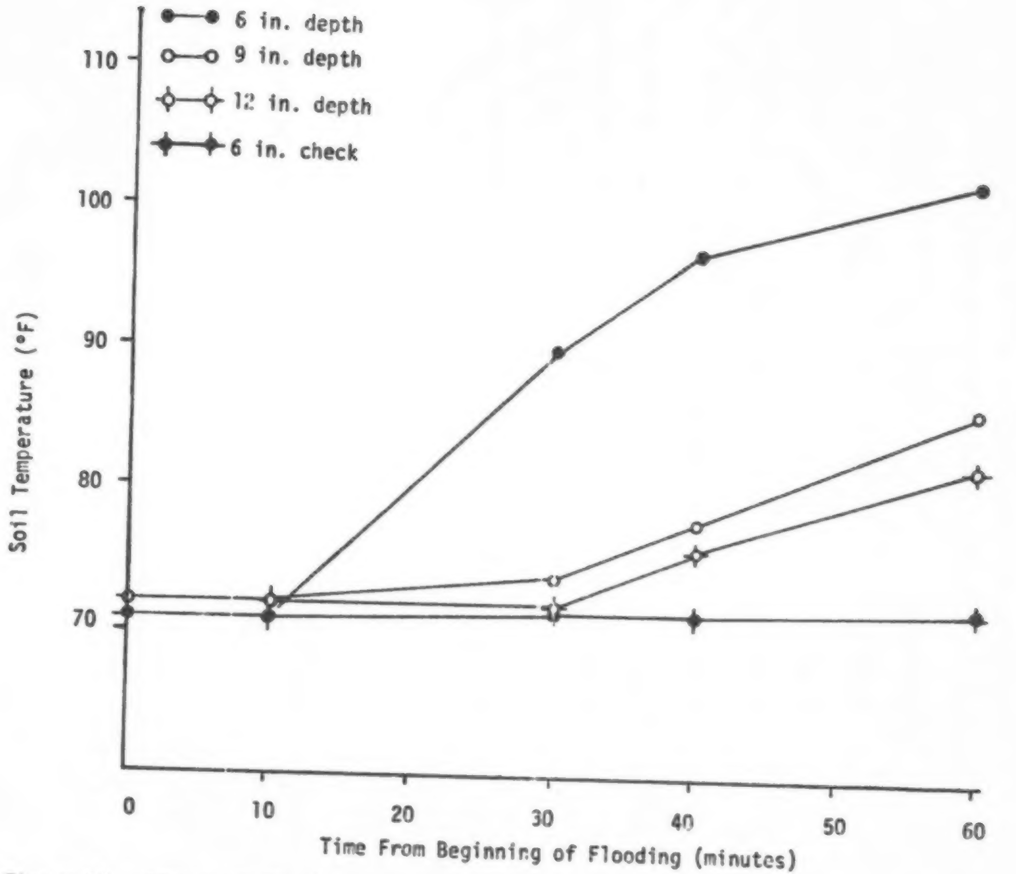


Figure 24. Effect of flood irrigating with 108°F water applied at rate of about 2 gpm on soil temperature.

Table 3. NATURAL PRECIPITATION AND SUPPLEMENTAL IRRIGATION RECEIVED BY FILBERTS DURING JUNE, JULY, AND AUGUST 1972

Date	Inches water	Date	Inches water
June 7	0.08	July 8	0.06
8	0.49	13	0.70 [z]
9	0.68	19 & 20	2.40 [z]
10	0.59	August 8	3.50 [z]
11	0.05	14	0.02
15	0.02	16	1.41
		20	0.27

---

[z] Supplemental irrigation.

forest tree species.[23] [24] Unlike dial-gauge dendrometers, this lever-type instrument is not affected by daily trunk shrinkage and always shows maximum radius attained by the trunk since the previous reading.

Dendrometers were installed on 5 different trees in cold and thermal water irrigated blocks and in the check block. Trees on which dendrometers were installed were picked for uniformity of size and vigor. The dendrometers were read 3 times each week starting in mid-July 1972.

Filberts were collected from 5 x 5 ft plots on the east side of 4 trees in the check, cold, and thermal water irrigated blocks on October 19, 1972. The plots were beneath trees with dendrometers. The nuts were counted; weighed at harvest; weighed after drying on January 3, 1973; and then cracked so the kernels could be examined.

Another study conducted in 1972 compared the effects of cold and thermal water sprinkler irrigation on growth and production of vegetable crops (see Soil Heat X Cool and Thermal Water Irrigation, Section VIII). The vegetable crops were: bush snap beans, 'Bluelake 274'; tomatoes, 'New Yorker,' 'C. 1327,' and 'H. 1350'; pepper, 'Calwonder'; cabbage, 'Golden Acre'; onion, 'Yellow Globe Danvers'; lima bean, 'Thaxter'; beets, 'Detroit Dark Red'; cucumber, 'Pioneer'; and sweet corn, 'Jubilee.'

Results

Some mechanical failures of equipment occurred in the early periods of the 1969 season. These included faulty valves, problems with branch saddles on the plastic subheaders, and line leaks; these adverse conditions were corrected without curtailing the demonstration. Inadvertent leaks in the system caused limited flooding of a small area with water at 125 to 130°F. Some cherry trees and bean plants were killed by the ponded water; sweet corn was only temporarily set back. In general, no adverse affects were observed from using thermal water sprinkler irrigation after the first season.

More emphasis was placed on proper scheduling of irrigations in 1970. Gypsum blocks and tensiometers were installed throughout the project to monitor soil moisture in the different crop areas. Table 2 lists the criteria used to schedule irrigations and Figures 25 and 26 show typical moisture curves for sweet corn and filberts.

Several tests were conducted to find the effect of thermal water irrigation on ambient air temperature in 1970. At night the air temperature often dropped below the optimum level for plant growth. By applying sprinkler applications of thermal water during these cooler night periods, it was thought that perhaps the heat given off from the thermal water would modify the air temperature and thus reduce the temperature drop. However, it was found that the thermal water heat release had no measurable effect on the air temperature during the periods observed (measurements made with minimum thermometers).

Soil temperatures beneath furrows irrigated with thermal and cool water were affected by the water applications (Figures 27 and 28). Within 2 hrs after initial application of 88°F water, the temperature at 6 in. beneath the furrow was 11°F above the check and after 5 hrs it was 16°F above the check (Figure 27). Temperatures at the 6 in. depth in the plant row increased 3°F after a 5 hr period. Cool 60°F water reduced soil temperatures by 6°F six inches beneath the furrow after 2 hrs and did not cause any further reduction in temperatures. No temperature reduction was caused in the plant row at 6 in. depth by the 60°F water at the end of 2 hrs, but soil temperature was 3° lower than check at end of a 5 hr application.

Soil temperatures at the 12 in. depth were not affected by water applications as much as at the 6 in. depth. The 88°F water increased soil temperature 12 in. beneath the furrows by 6°F and the cool 60°F water decreased temperatures by 8°F after 5 hr application (Figure 28). Soil temperature at 12 in. depths in the plant row, halfway between furrows, was not altered by either 88°F or 60°F water (Figure 28).

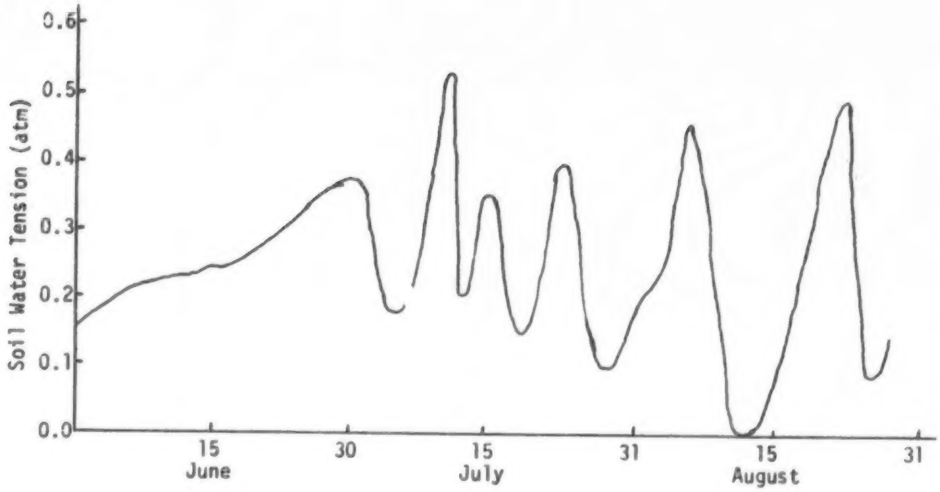


Figure 25: Soil Moisture Curve at One Foot Depth in Sweet Corn Field.

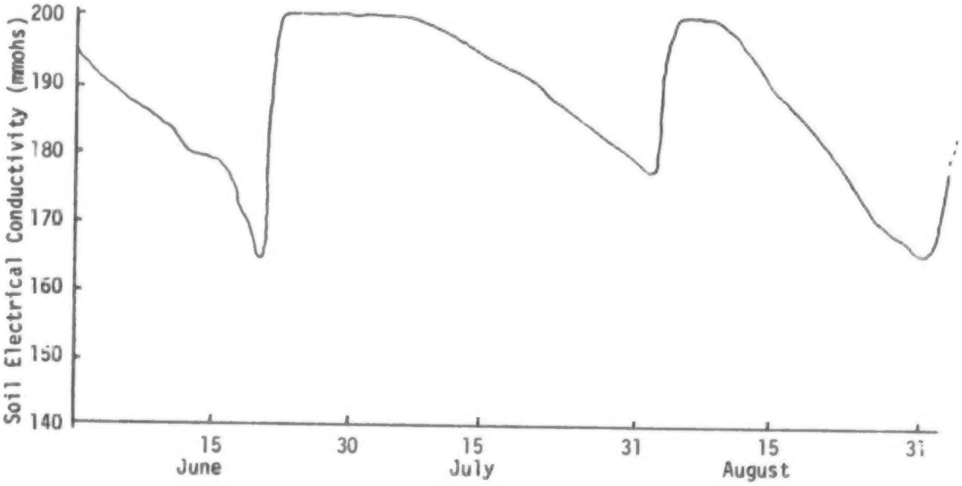


Figure 26: Soil Moisture Curve at 18 Inch Depth in Filbert Orchard.

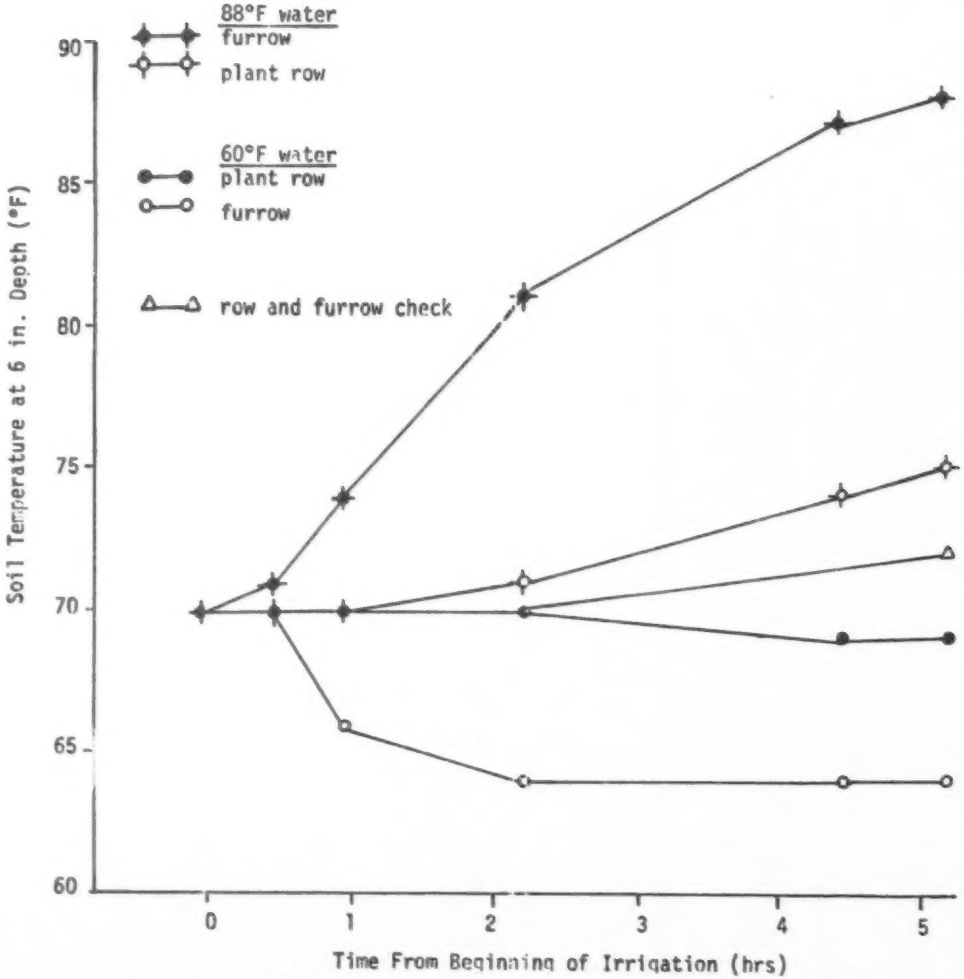


Figure 27. The effect of 60° and 88° water applied in furrows on soil temperatures 6 inches beneath furrow and plant row.

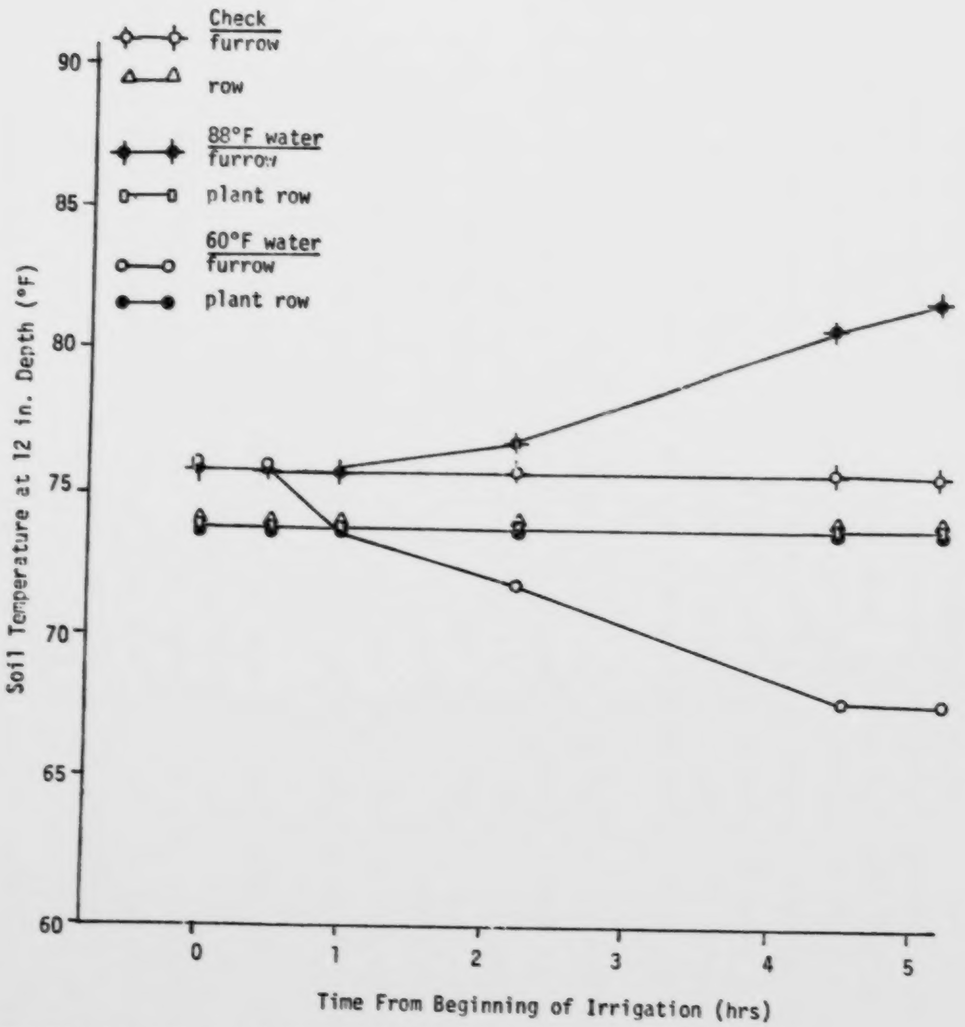


Figure 28. The effects of 60° and 88°F water applied in furrows on soil temperatures 12 inches beneath furrow and plant row.

The sensors 12 in. beneath the furrow were actually 2 to 3 in. closer to the thermal water pipe than were sensors 12 in. beneath the plant. The movement of heat from the buried pipes may have contributed to the 2° difference between furrow and plant row checks at the 12 in. depth. Apparently the plant row and furrow checks at 6 in. were not influenced in the same manner (Figure 27).

Since the trial was on soil heated by circulation of thermal water through buried pipes, the vertical soil temperature profile was somewhat different than normally encountered in unheated soil. The 24 in. soil profile heated by thermal water was generally several degrees warmer than non-heated soil (Figure 29). In unheated soil, temperatures were about the same or slightly cooler at 24 in. as at the 12 and 6 in. depths. In heated soil, the 24 in. depth was generally warmer than at the 12 in. depth and as warm or warmer than the 6 in. depth.

Because of heat emitted from the buried pipe, the 60°F irrigation water had to absorb increasing amounts of heat as depth of water penetration increased. The heat from the buried pipe may have also influenced soil profile temperatures where thermal irrigation water was used. The effect of 60°F and 88°F water on soil profile temperatures could not be separated from the effect of heat flow from the soil heating pipe because it was not possible to duplicate the trial on unheated soil in 1971.

The 60°F irrigation water apparently reached an equilibrium of 69°F twelve inches beneath the furrow after about 4-1/2 hr, and an equilibrium temperature of 64°F six inches beneath the furrow about 2 hr after irrigation started. With 88°F water equilibrium temperatures at 6 and 12 in. beneath the furrow were not reached at the end of 5-1/4 hr.

No visual plant damage was noted in any of the plant furrows irrigated with the thermal water (88°F).

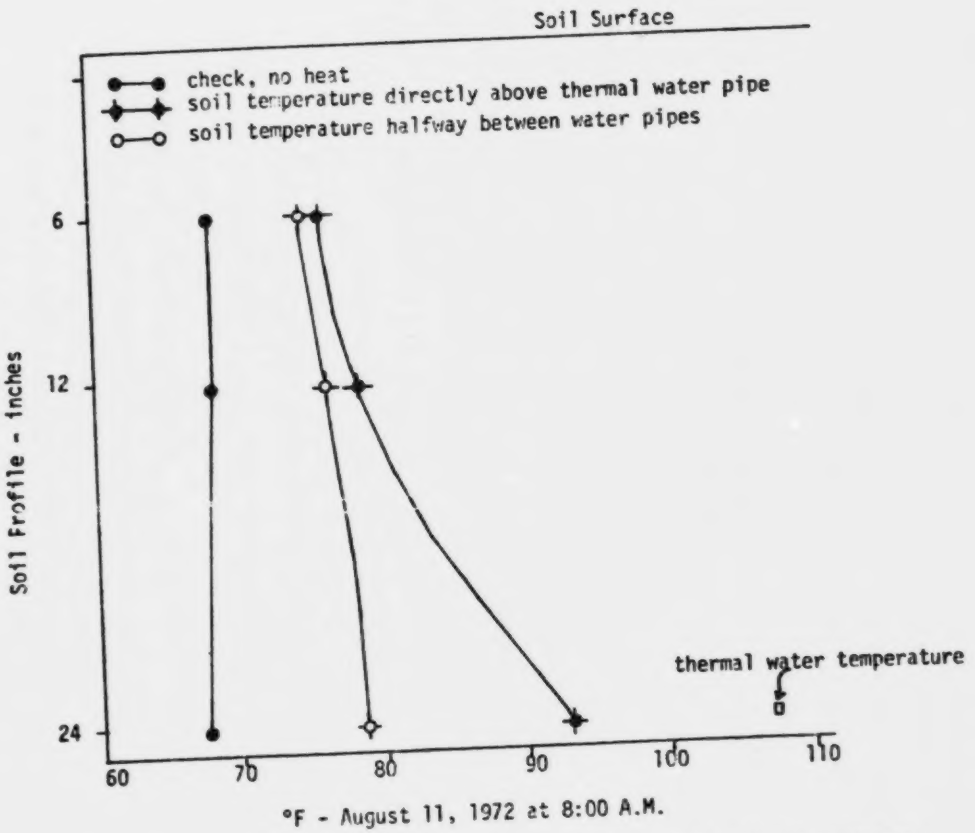


Figure 29. Comparison of non-heated soil temperature profile with temperatures of soil heated with thermal water circulated through 2 inch diameter PVC pipes, 5 feet apart, buried 24-26 inches deep.

Even in the study where a high application rate of 108°F water was applied to tomatoes, there was no apparent visual damage to plant and none developed later in the season from the thermal water.

The rate and amount of heat penetration in the soil is closely related to volume and temperature of water applied. Temperature alterations caused by irrigation water take place slowly at depths of about 12 in.; however, soil surface temperatures were rapidly modified. Although no plant damage was noted here, some crops may be more sensitive than soybeans or tomatoes to surface thermal water applications.

Soil moisture levels for the 1972 non-irrigated check, thermal, and cold water irrigated filbert blocks are shown in Figures 30, 31, and 32. Soil moisture at the 6 in. depth in thermal and cold water irrigated plots was about the same through July and August. Soil moisture level at 18 and 24 in. depths was somewhat lower in the cold water block during August than in the thermal water block (Figure 32 vs 31). By the end of July and throughout August, moisture levels in the surface 24 in. were low (Figure 30) in the non-irrigated check. The high value for August 17 in Figure 30 was caused by 1.41 in. of rain that fell on August 16, 1972.

The average accumulative radial trunk growth made by trees under the various treatments is shown in Figure 33. The slightly lower moisture levels recorded at 18 and 24 in. depths in the cold water compared to the thermal water block (Figure 32 vs 31) apparently did not reduce radial trunk growth (Figure 33). There was no significant difference in radial trunk growth made by trees irrigated with thermal and cold water (Table 4). Trunks of trees from the non-irrigated check plot grew 66 to 70 percent less than irrigated trees.

Table 5 contains filbert yield data from the various treatments. Size and vigor of all sample trees were judged to be nearly equal when selected in June, and average diameter of tree foliage spread was about

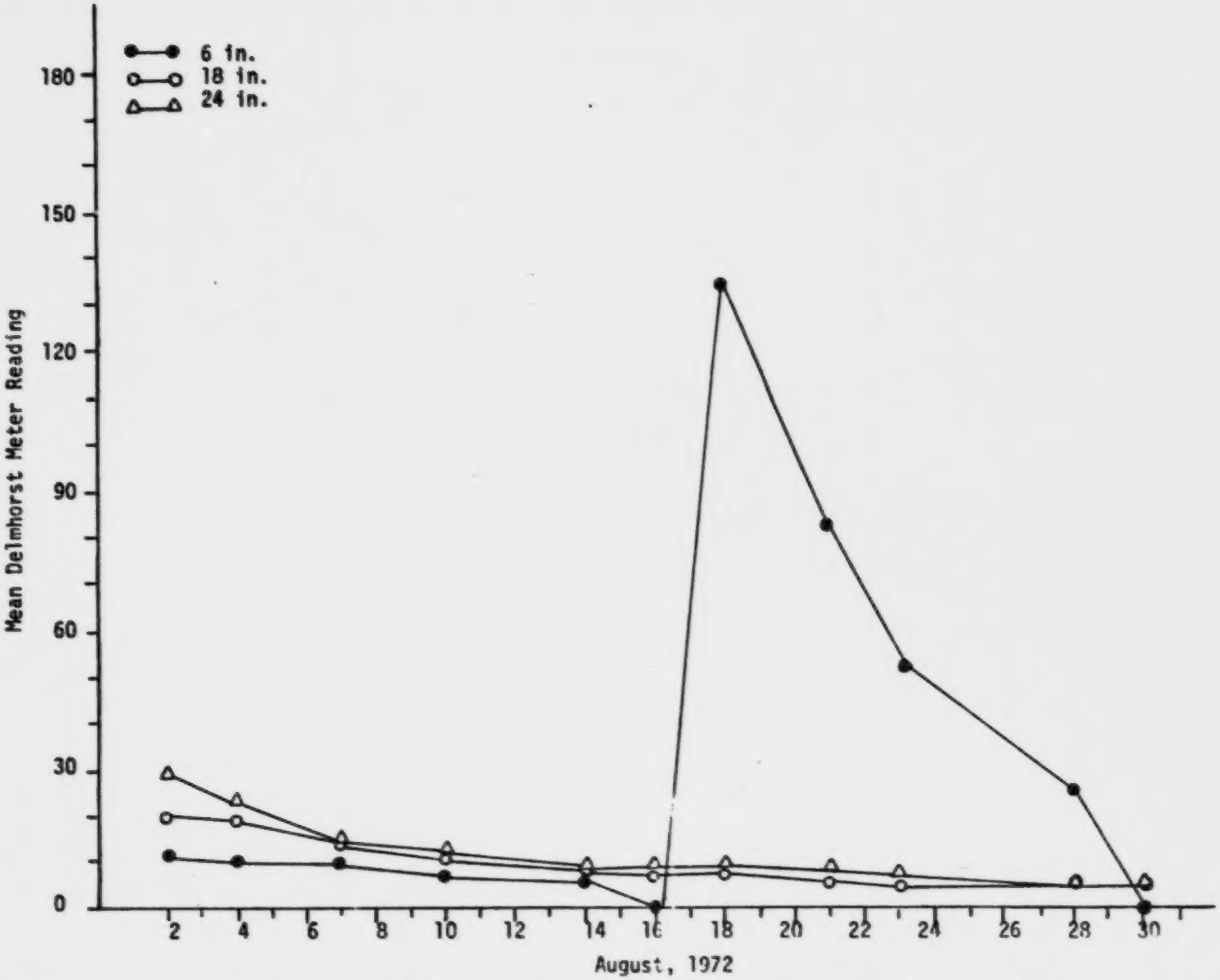


Figure 30. Delmhorst meter readings in non-irrigated check block of filberts at three depths.

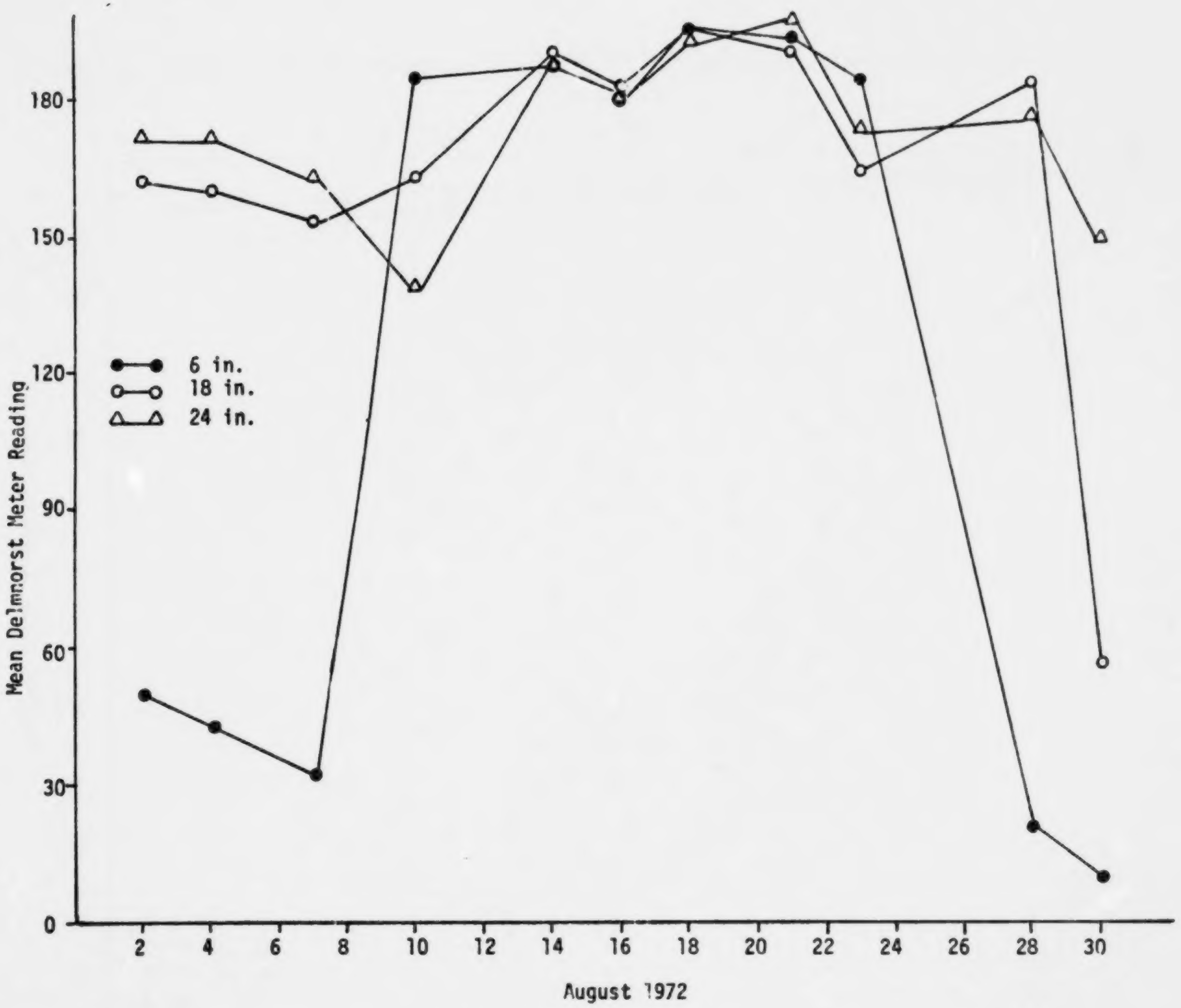


Figure 31. Delmhorst meter readings in thermal water irrigated block of filberts at three depths.

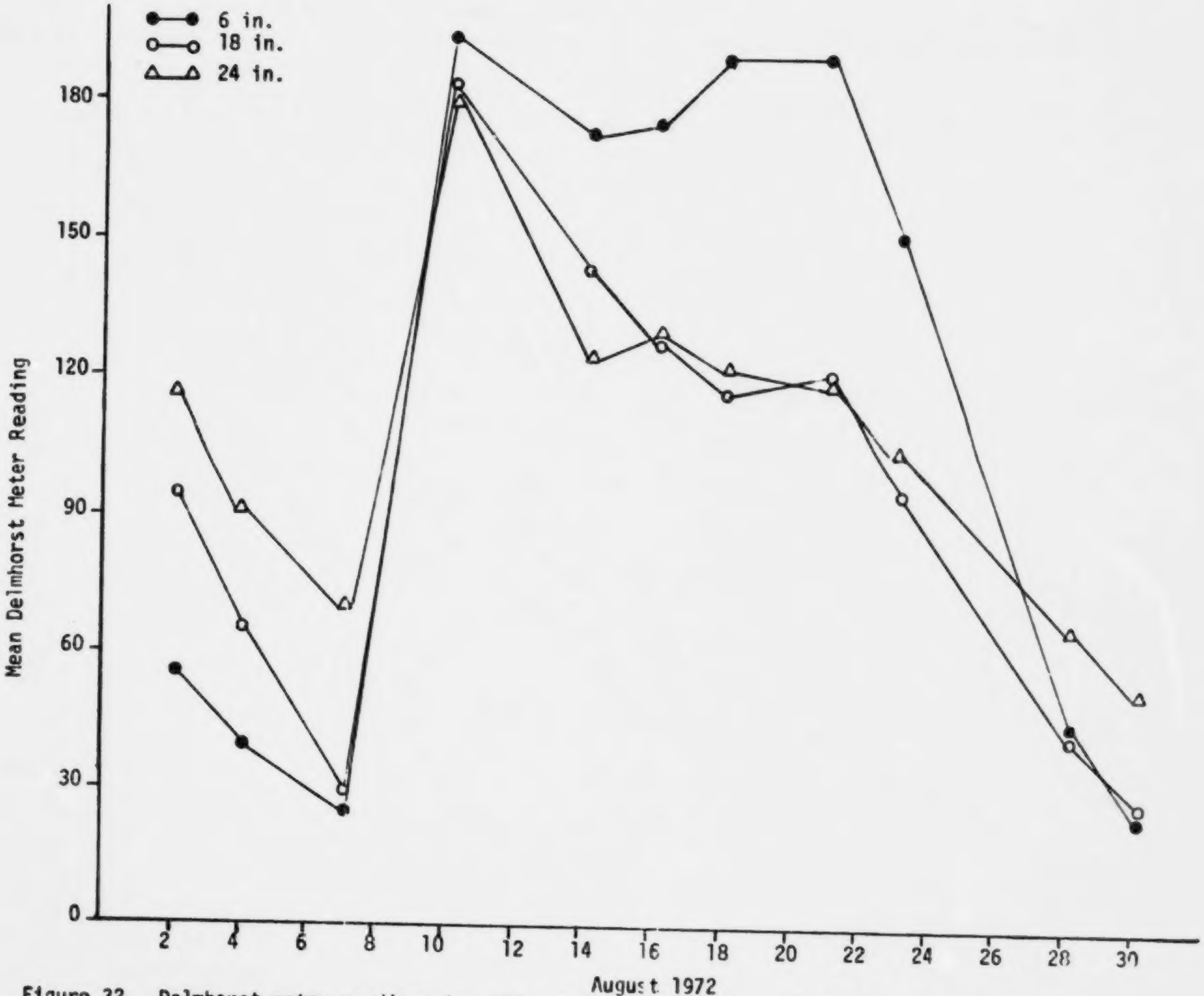


Figure 32. Delmhorst meter readings in cold water irrigated block of filberts at three depths.

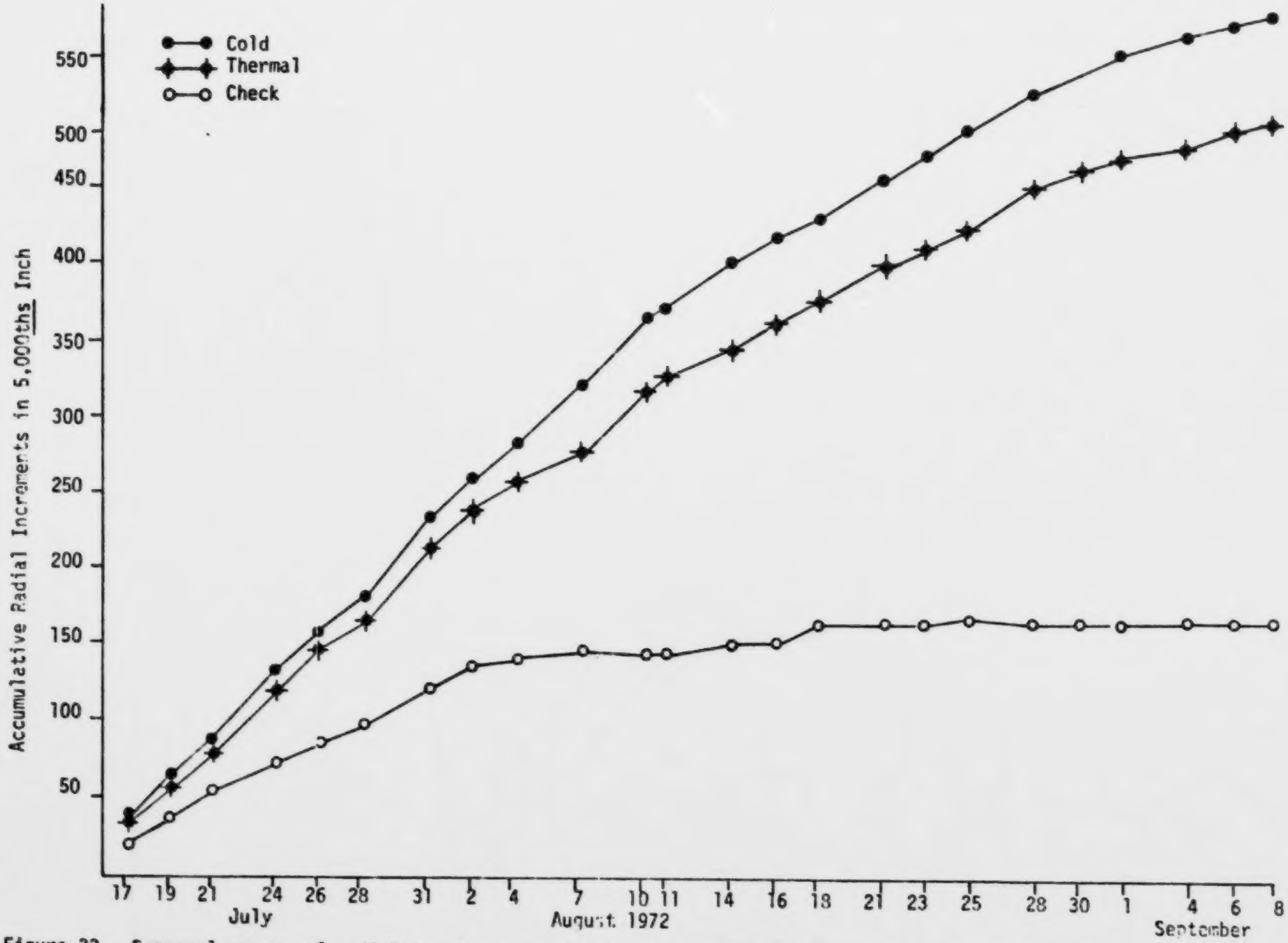


Figure 33. Seasonal curves of radial trunk growth of filbert trees (10-12 years old) grown on non-irrigated check plots and on thermal and cold water irrigated plots.

Table 4. AVERAGE ACCUMULATIVE RADIAL TRUNK GROWTH MADE BY 10-12 YEAR OLD FILBERT TREES IRRIGATED WITH THERMAL AND COLD WATER AS COMPARED TO TRUNK GROWTH MADE BY NON-IRRIGATED TREES

Irrigation Treatment	Average accumulative radial trunk growth - 1/5,000 inch[z]
Cold water	579.6 a
Thermal water	505.8 a
Non-irrigated check	169.6 b

[z] Means followed by different letters are significantly different at 1% level - Duncan's Multiple Range Test.

Table 5. YIELD OF FILBERT NUTS FROM COLD AND THERMAL WATER IRRIGATED BLOCKS COMPARED TO YIELDS FROM NON-IRRIGATED CONTROLS

Irrigation treatment	Avg. foliage spread of trees, diameter - ft	Nut yield/plot[z] at harvest-10/19/72		Avg. dry wt (g) plot[z] January 3, 1973			Avg. number/plot[z]	
		No.	Wt-g	Gross	Shell	Kernel	Shrivels	Blanks
Thermal water	16.2	132.2	556.2	452.8	279.9	168.0	3.2	17.5
Check	15.6	120.7	556.2	430.0	277.8	146.5	8.2	18.7
Cold water	16.4	96.0	461.2	378.3	238.8	134.0	4.0	14.0

[z] Plot size 5 X 5 ft.

equal in all treatment blocks in October (Table 4). Average nut yield was not significantly influenced by irrigation treatments. However, there was a below average crop of nuts in 1972 because fruit buds were damaged by an early freeze the previous fall. Perhaps irrigation would have made a greater difference in production if a heavy nut crop had existed. Individual nut kernel size was not influenced by irrigation and the percentage of blank nuts was about the same for all treatments. Tree trunk growth was increased by the irrigations (Table 4), and after several seasons with irrigation, yields might be influenced by greater tree vigor.

A severe cold period with -12°F occurred in December 1972 and probably eliminated or greatly reduced the chances for a good filbert crop in 1973. Thus, it will be difficult to judge if the irrigations and extra growth made in 1972 will benefit the crop in 1973. It can be safely said that thermal water, which is considered to be a pollutant to rivers, was not harmful to filbert trees or crop in 1972.

PLANT COOLING

Crops are frequently injured by excessive transpiration during periods of high temperature and low humidity. Associated high solar radiation received directly by the plant as well as that reflected and reradiated from the soil surface contributes to the high water loss. Even when soil moisture is adequate, diurnal wilting of plant (caused by excessive transpiration during hot dry weather) may cause permanent damage if the condition persists.[25] Plant growth rate decreases with increase in temperature above approximately 88°F for a very wide range of crops (Figure 34). Sprinkler applied water can be used to create a more favorable microclimate for plants by lowering temperature through evaporation, increasing humidity, and minimizing plant water loss through transpiration. The more favorable microclimate is induced by applying light and sometimes intermittent applications of water during periods of high temperatures and low humidity.

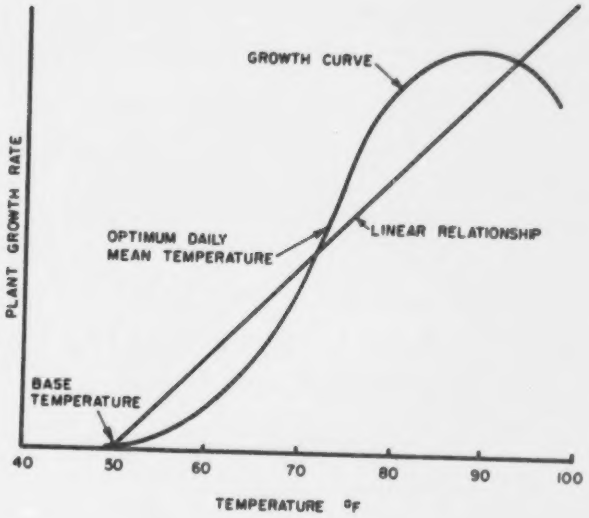


Figure 34: Plant Growth Rate as Related to Air Temperature

During periods of high atmospheric stress, flowers and small pods of snap beans drop from the vine. Applications of .04 to .06 in. of water per hour from 10:00 a.m. to 3:00 p.m. during bloom and pod development, when atmospheric stress was high, resulted in a 22 to 52 percent increase in snap bean yields.[26] Sprinkling reduced atmospheric stress by reducing temperature and raising humidity and resulted in a greater yield.

Potatoes are benefited by cool temperatures which minimize their sugar loss from high respiration, a well aerated soil to promote tuber development, and conditions that favor low transpiration. In experiments on muck soil in which light sprinkling was practiced during the growing season when air temperatures were above 85°F and the relative humidity below 50 to 60 percent, the yield of No. 1 tubers of the 'Sebago' cultivar was increased by 44 percent.[26]

Misting or light irrigations may not be advisable for all crops. The onion, a warm weather crop, was not benefited by a cooler microclimate induced by misting. Misting reduced bulb yield by 50 percent.

In review of the possible deleterious effects of high temperatures and subsequent low relative humidities, the initial plan of operation for the project included plant cooling and relative-humidity control. By applying light applications of water during high temperature periods, relative humidity is increased and temperature decreased. The plant is then able to maintain turgor, keep its stomates open for gas exchange, and withdraw the needed water from the soil without undue stress.

Thermal water was used to cool pole snap beans, tomatoes, cabbage, corn, apples, and peaches at various times during the operation of this demonstration project.

Procedure

Thermal water was used for plant cooling of pole snap beans, sweet corn. and a walnut orchard in 1969 and 1970. Over-crop sprinklers were used for vegetable crops and under-tree sprinklers were used in the walnut orchard for plant cooling. Hygrothermographs and minimum and maximum thermometers were placed in pole snap bean and sweet corn fields and in the walnut orchard in 1970 to measure cooling effect of the water. Temperature and humidity measurements were recorded inside a standard U.S. Weather Bureau shelter at a height of about 5 ft.

The influence of cold and thermal irrigation water on temperatures 1, 5, 10, and 20 ft above the ground was recorded with the Delta-temperature system on September 15, 1972. The irrigated blocks were 48 ft wide (east-west) and 218 ft long (north-south). Control, thermal, and cold water irrigated blocks were separated by two rows of sweet corn that were 7 to 9 ft tall. Temperatures were recorded by shielded thermistors near the middle of each block. Non-irrigated check block temperatures were recorded in an open area west of the irrigated blocks.

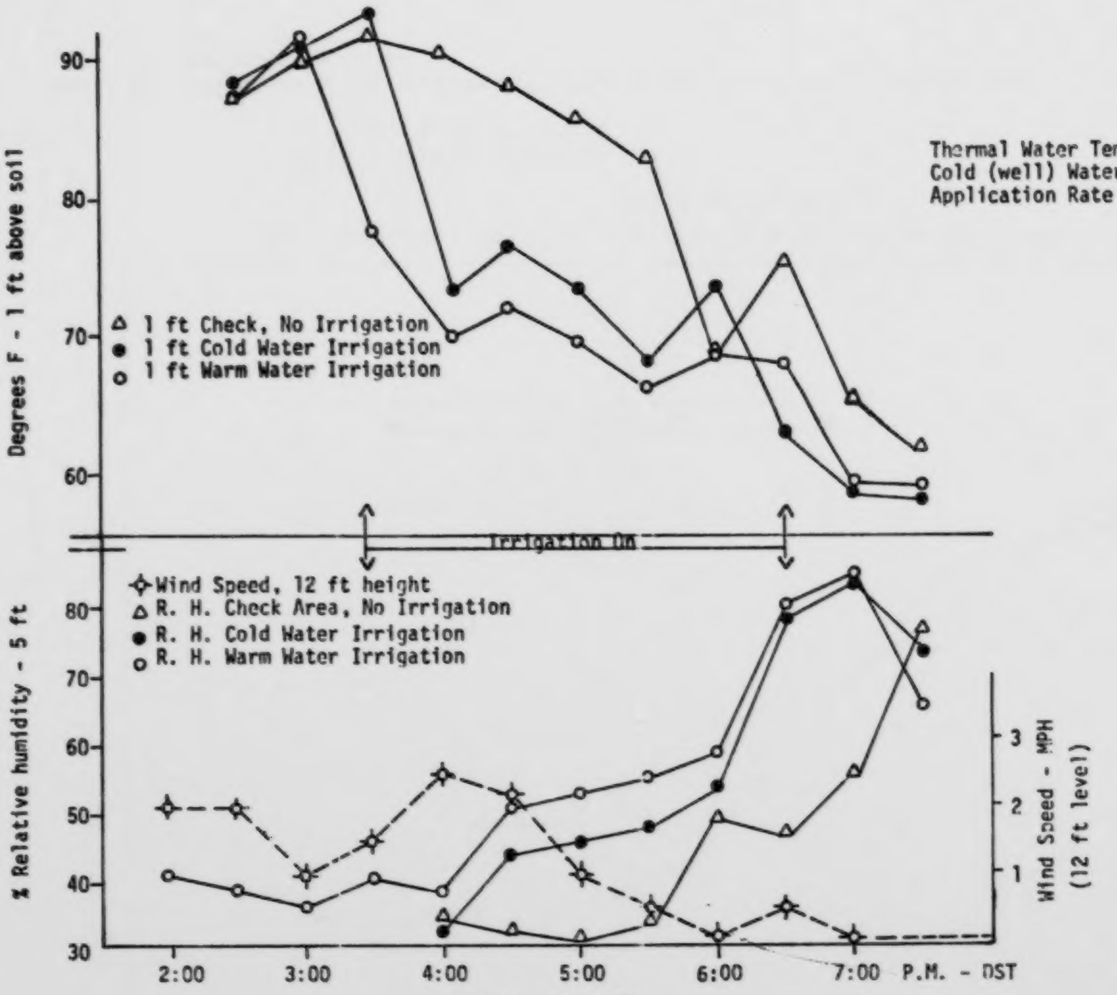
Thermal water temperature was 88 to 90°F and cold well water was 56°F at the sprinkler head on September 15, 1972 (Figures 35 through 38). Sprinkler heads were 18 in. above ground and water application rate was about .25 in. per hr.

Some high variable clouds were present during the irrigation and did influence air temperatures.

Results

Thermal water serves as a cooling agent in two respects: 1) it is cooler than ambient air temperature on contact with the plants, and 2) it increases the wetted surface area and by so doing increases evaporation in the plant environment. The heat necessary for evaporation (539 cal/gm or 971 Btu/lb water vaporized) is drawn from the surrounding air, plants, and soil.

In July 1969, 86°F was exceeded only 4 times and on these dates the sprinklers over the pole bean fields designated for plant cooling



Thermal Water Temperature - 88-90°F
Cold (well) Water Temperature - 56°F
Application Rate - .25 in/hr

Figure 35. (Upper) Temperatures one foot above the ground in cold and thermal water irrigated, and non-irrigated blocks.
(Lower) Wind speed recorded adjacent to irrigated blocks and relative humidity in irrigated and control blocks on September 15, 1972.

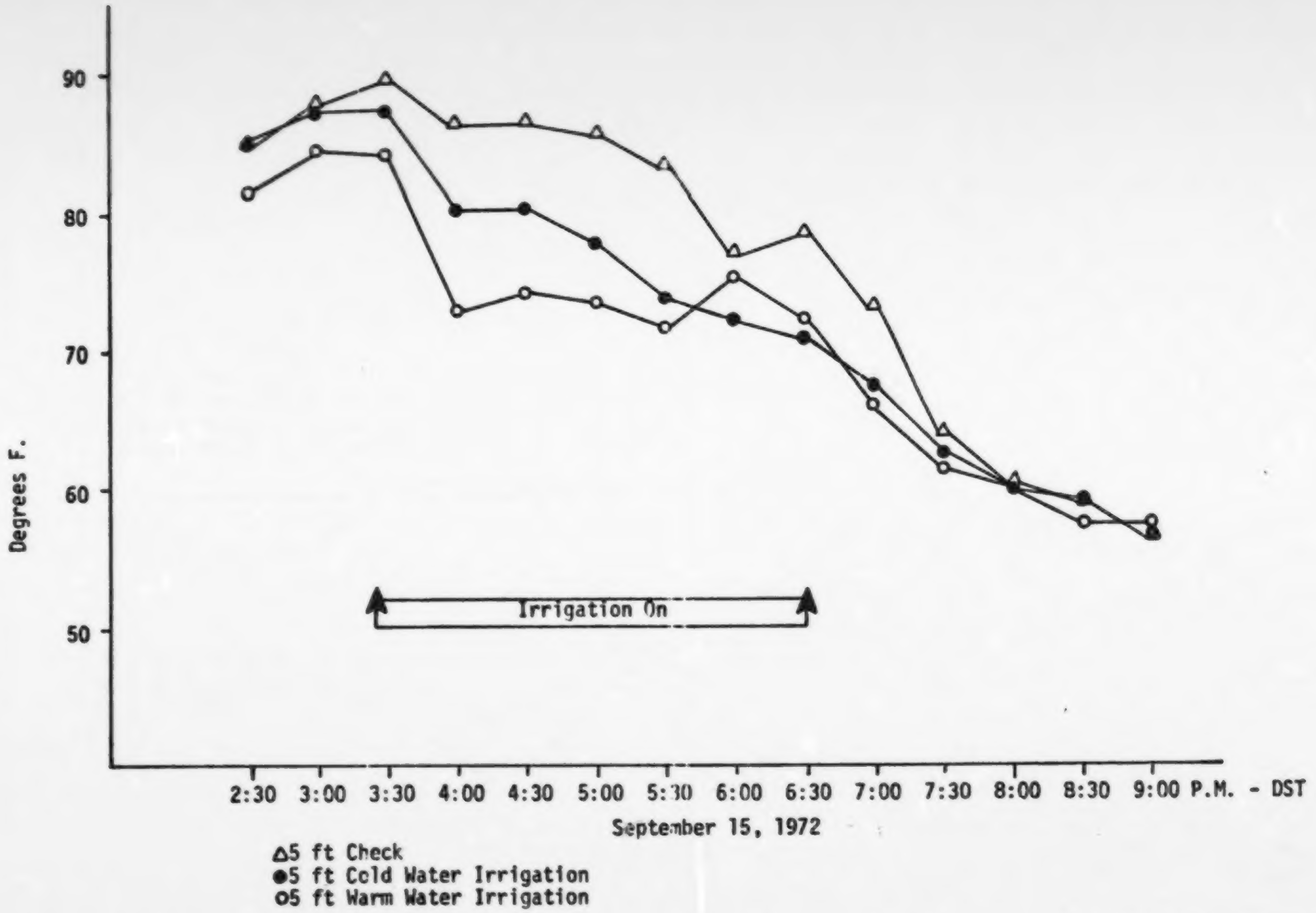


Figure 36. Comparison of temperatures 5 ft above ground in cold water, thermal water, and non-irrigated blocks on September 15, 1972.

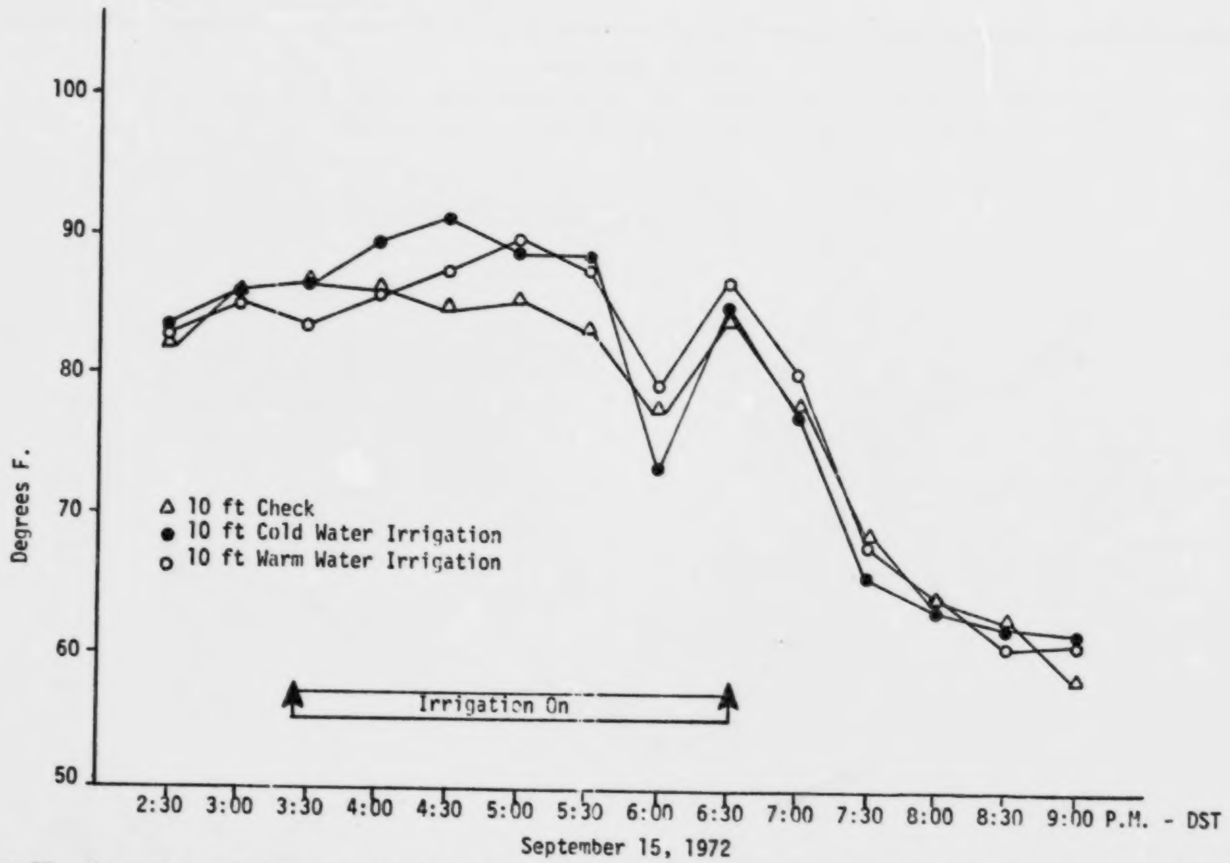


Figure 37. Comparison of temperatures 10 ft above ground in cold water, thermal water, and non-irrigated blocks on September 15, 1972.

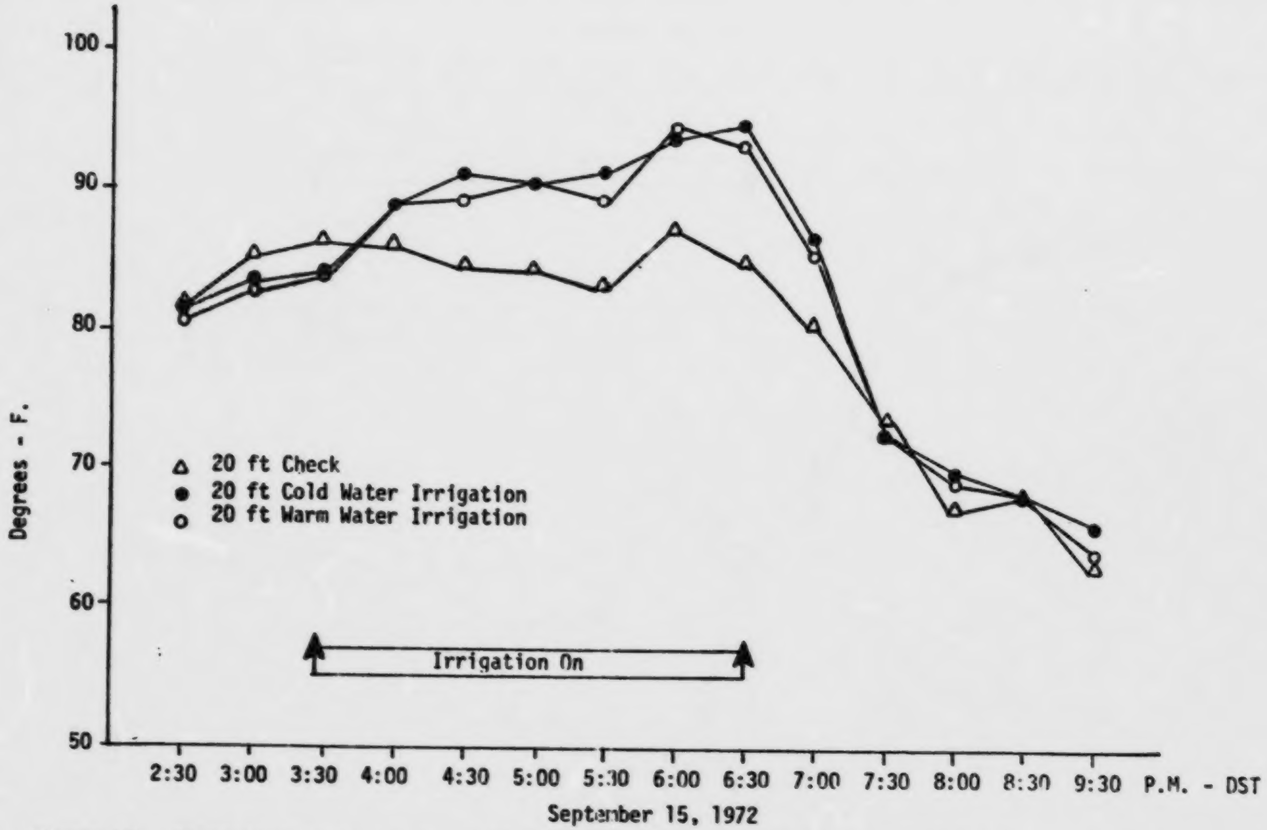


Figure 38. Comparison of temperatures 20 ft above ground in cold water, thermal water, and non-irrigated blocks on September 15, 1972.

demonstration were activated as were those in the designated orchards. A temperature decrease of 4 to 6°F and a relative-humidity increase of up to 20 percent were recorded in sprinkled areas.

August 1969 was a cool month and temperatures greater than 86°F occurred only six times. On the last four of these occasions, the pole beans were not sprinkled because harvest had been completed. The pears, cherries, and early apples had also been harvested by this time. The walnuts and filberts had reached full size and the shells were in the hardening process. Therefore, no plant cooling was attemped in these orchards.

The effect of thermal water on temperature in a pole bean field in 1970 is shown in Figure 39. Air temperature was reduced from 90 to 82°F while the temperature in an adjacent field continued to climb to 92°F. Immediately after activation of the sprinklers located above the bean rows, the humidity rose from 40 to 65 percent. In the control areas, the humidity fell to 32 percent.

Under-tree sprinklers located in the walnut orchard produced air temperature and humidity changes similar to those recorded in the bean field (Table 6). No increase in fungus, mold, bacterial infestation, or any other detrimental effects were noted in any of the crops that were cooled by the application of thermal water.

The effect of thermal and cold water on air temperature was compared with each other and with temperatures in a non-irrigated area on September 15, 1972. One-foot-level air temperature in the check block at 5:30 p.m. (Figure 35) was 82.5°F and at 6:00 p.m. had dropped to 68°F. By 6:30 p.m., the temperature was back up to 75°F. This temperature fluctuation was caused by a passing cloud. When the check temperatures dropped, there was a corresponding rise in relative humidity.

Wind speed also contributed to some temperature fluctuations. Wind speed was recorded 12 ft above the soil surface and ranged from about

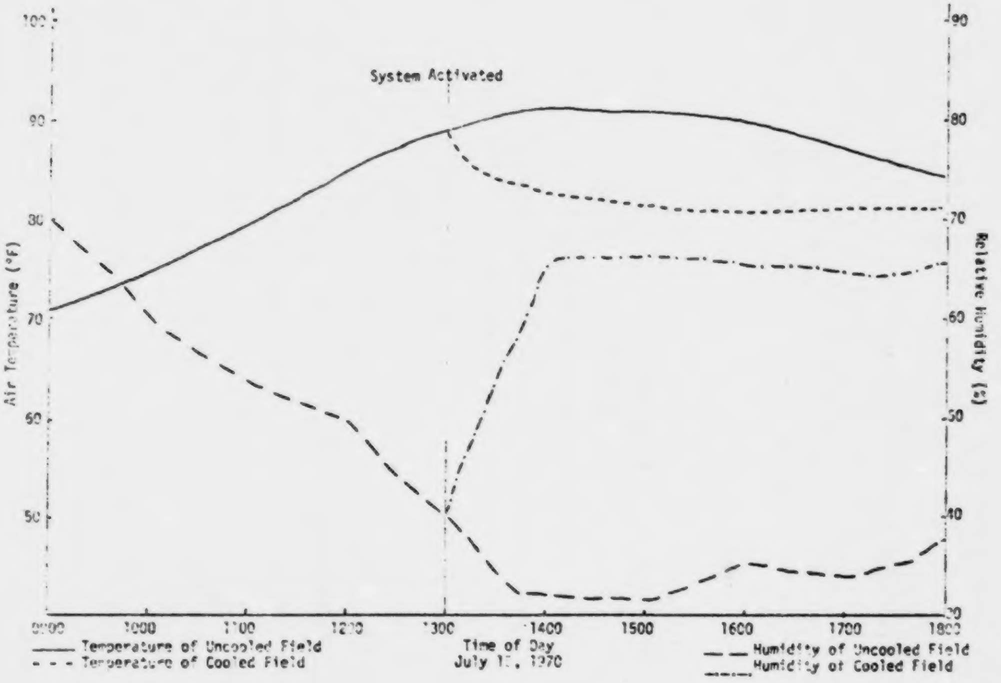


Figure 39: Plant Cooling with Thermal Water in Pole Bean Field.

Table 6. PLANT COOLING WITH THERMAL WATER IN WALNUT ORCHARD

	Maximum Air Temperature (F)		Minimum Relative Humidity (%)	
Date	Normal ambient	Cooled orchard	Normal R.H.	Cooled orchard
August 10	95	85	21	48
August 12	86	80	21	47
August 14	82	76	30	53
August 15	89	80	20	47

.5 to 2.5 mph. Wind was from the west and southwest during the irrigation period. At 4:00 p.m. wind speed increased to an average of about 2.5 mph.

Temperatures in the irrigated block dropped relatively more than in the control area at 4:00 p.m. The increased wind speed probably caused more rapid evaporative cooling of the irrigation water and depressed temperatures in irrigated blocks (Figure 35).

Temperatures at the 1 ft level were near 90°F in all blocks before the irrigation was started. Shortly after irrigation started (4:00 p.m.), temperatures in the cold and thermal water blocks dropped 15 to 20°F at the 1 ft level. Control temperatures dropped about 1°F. By 4:00 p.m. relative humidity reached 20 to 25 percent higher than in the non-irrigated control block at the 5 ft level.

One foot level temperatures in the thermal water block tended to be slightly cooler and humidity slightly higher than in the cold water block.

Temperature fluctuations and differences between irrigated and non-irrigated blocks were not as great at the 5 ft level as at 1 ft (Figures 35 and 36). Temperatures in the thermal water block were about 11 to 12°F cooler, and cold water block temperatures were 6 to 8°F cooler than in the control block through most of the irrigation.

The influence of increased wind at 4:00 p.m. and the clouds about 6:00 p.m. on 5 ft level temperatures can be seen in Figure 36, but the temperature depressions are not as large as occurred at the 1 ft level.

The cloud influence on 10 ft level temperatures at 6:00 p.m. was not detectable (Figure 37). Temperature differences among blocks were not large or consistant at the 10 ft level. Temperatures at the 20 ft level tended to be warmer above the irrigated plots than above the control block (Figure 38).

SECTION V

UNDERSOIL HEATING

Recent experimentation with undersoil heating has indicated that significant increase in plant growth can be realized with relatively small increases in soil temperature. Boersma[27] found that soil heating had significant effects on the yield and maturity of several crops but concluded that long-term studies must be made to determine the relationship between soil temperature and other variables involved in plant production. Much of Boersma's work was carried out with heating cables spaced 6 ft apart and 3 ft deep.

An underground thermal water pipe grid system was a logical combination with warm water irrigation since the hot water would be available at each distribution point where above ground irrigation lines are attached. For this project, a pilot plot of approximately two acres was chosen to demonstrate the field use of thermal water. Figure 40 shows the area in which an underground thermal water pipe grid system was installed. It was hoped that the effect of heated soil on extending the growing season, accelerating germination of seedbeds, and increasing yields could be demonstrated under field conditions. In addition, this is an economically attractive method for utilizing another portion of the warm water effluent that will become increasingly available as more power plants are put on stream.

DESIGN INFORMATION AND ASSUMPTIONS*

1. Temperature--The following temperatures were selected for heat transfer calculations:

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* This section is derived from sources listed in Soil Heating Literature Survey on pages 102 and 103.

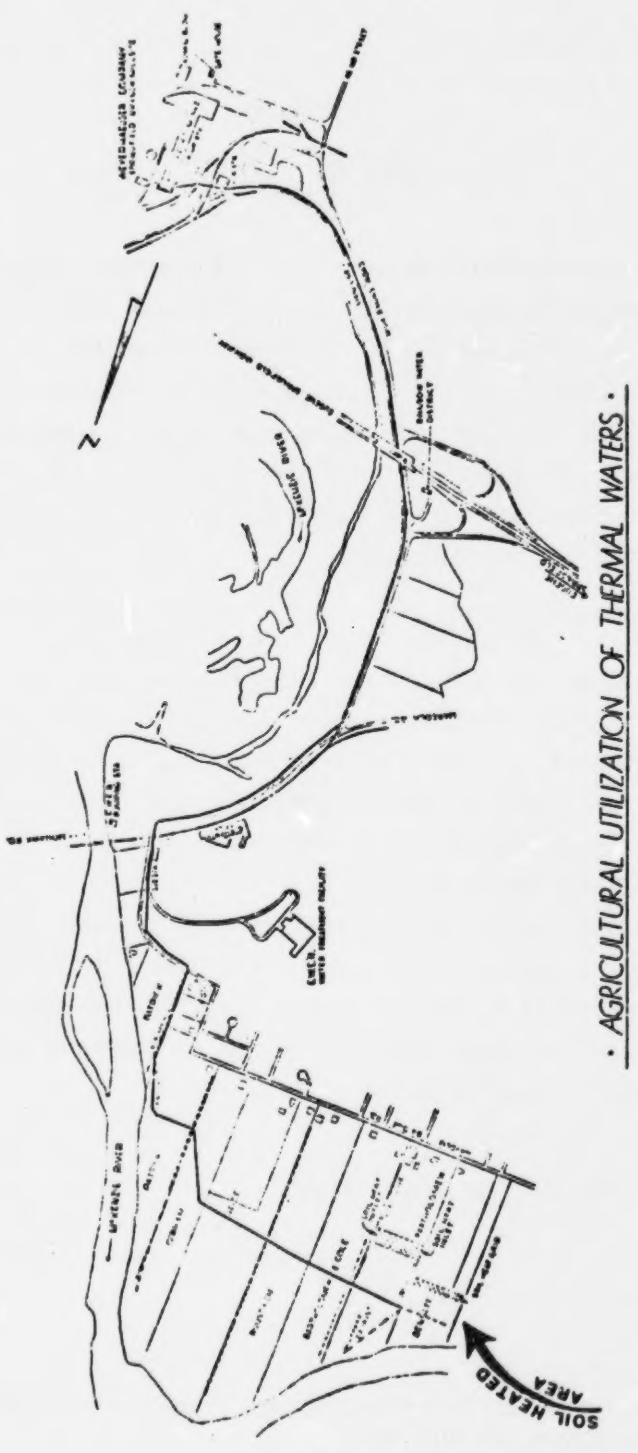
· AGRICULTURAL UTILIZATION OF THERMAL WATERS ·
SOIL HEATED AREA
N
SEWER

Figure 40. Location plan

a. Mean low air temperature at Springfield, OR, during February (the earliest one might expect to plant seed is 35°F).

b. Optimum seed germination temperature ranges from 53 to 59°F with an average of 56°F.

c. Maximum soil temperature at 18 in. below soil surface to be 84°F.

d. Soil surface temperatures will not vary more than 2°F at any point above the pipe grid system to obtain the best practical uniform growth.

2. Soil--The soil in the 2-acre plot selected for the demonstation is sandy loam.

3. Thermal conductivity of soil (k_s) is 1 Btu ft/ft^2 hr °F.

4. Hot water effluent temperature is 100°F ± 10°F.

5. Pipe grid system depth--24 in. below soil surface.

6. Water supply--Installation of tie-in to be located in the main water supply header near the 2-acre plot where the pressure head is approximately 100 psig.

Selection of Pipe Material

Aluminum, galvanized, and PVC pipe were investigated as possible materials for the piping grid system. PVC pipe has some excellent properties since it is corrosive resistant and lends itself to easy installation; however, its heat transfer characteristics and strength are quite inferior to that of any metal pipe.

At higher temperatures, PVC loses fiber strength and, therefore, the equivalent amount of working pressure (Figure 41). Pipe fabricated of PVC is not recommended for use at temperatures above 140°F.

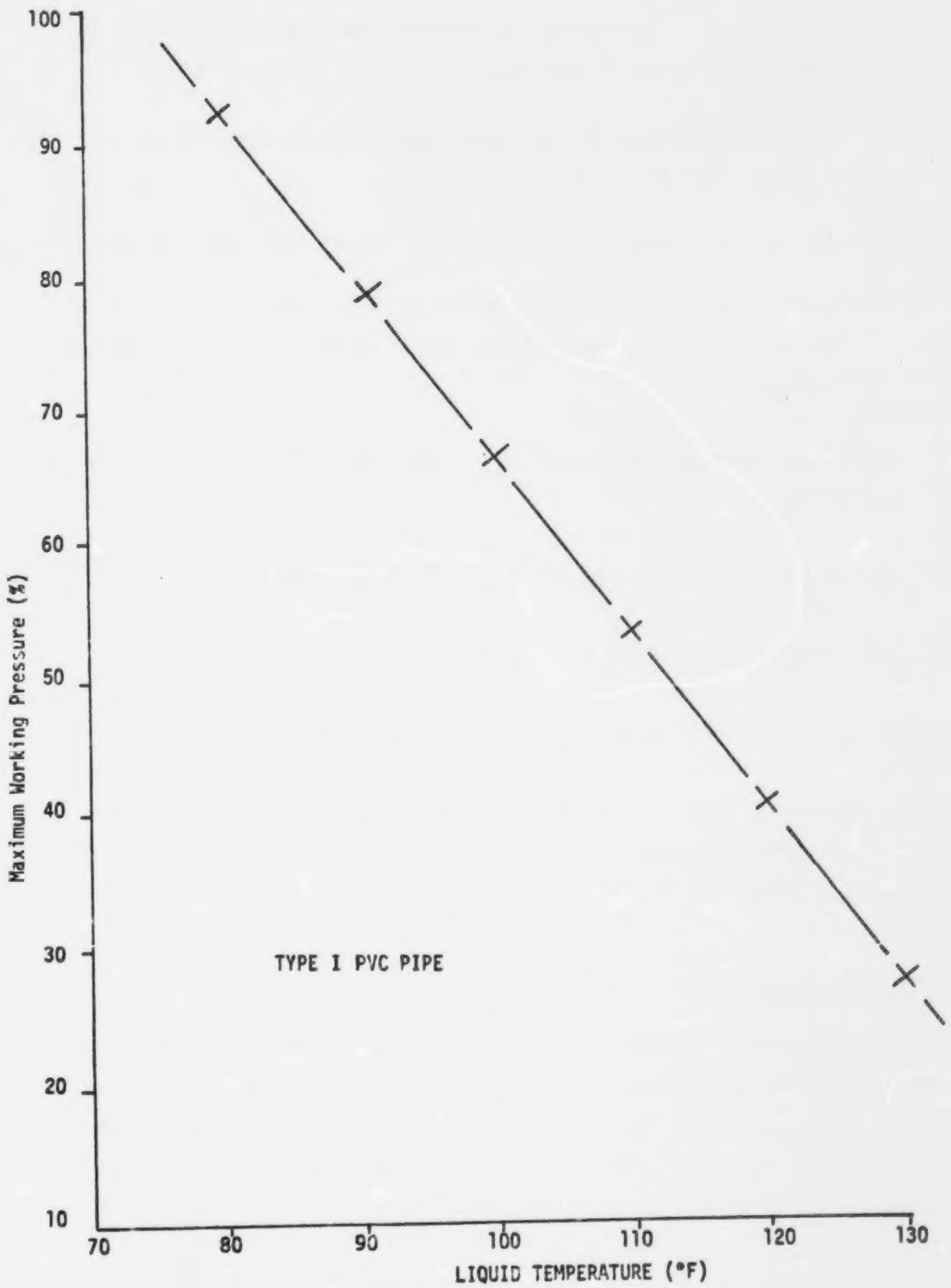

Figure 41: Temperature of pipe as related to working pressure.

The thermal conductivity of PVC is approximately 0.08 Btu ft/hr ft^2 °F compared to 118 for aluminum and 30 for iron. Calculations indicate that there should be a 26°F temperature drop across the wall of buried Schedule 40 PVC pipe that carries water at 100°F. In comparison, there is less than a 0.1°F drop across the wall of the aluminum or galvanized steel pipe.

Aluminum suppliers recommend a soil analysis before considering the use of aluminum pipe. Some types of soil (cinders, mine wastes, and others) are specifically not suitable for the burial of bare aluminum pipe. Cathodic protection may be required in soils that have a specific electrical resistance lower than 1500 ohm cm. Alclad aluminum pipe does, however, provide its own cathodic protection for soil burial conditions. Alclad pipe is 6061 aluminum pipe with a 5 percent thick cladding of high purity aluminum containing 1 percent zinc. Aluminum piping can be either joined by Swage-Bond Process or welded.

Zinc-clad steel pipe is the only type extensively used for underground applications. However, even galvanized pipe will deteriorate rapidly in some soils and galvanic protection may be necessary for long service life.

Unit material and installation costs for 2-1/2 in. diameter pipe are approximately \$2.20, \$1.80, and \$0.68 per ft respectively for aluminum, galvanized steel, and PVC used in an agricultural or farming type installation. Aluminum and galvanized pipe are most attractive from the standpoint of heat transfer. However, the extreme differences in requirements for corrosion control in different soil areas is a problem for standardizing a system. Therefore, in order to standardize on a workable system for all soil conditions and to minimize the captial investment, PVC was chosen for the demonstration plots.

Heat Transfer

The design basis giving no more than 2°F variation in soil surface temperature required a grid system of pipes 24 in. below the surface and

5 ft apart (Figures 42 and 43). The heat transfer from each pipe was calculated from the following heat transfer equation for the steady transfer of heat from buried isothermal heat sources to the air:

$$q = \frac{t_w - t_A}{R_o}$$

where:

q = Heat Flow, $\frac{\text{Btu}}{(\text{hr})(\text{ft of pipe})}$

t_w = Water Temp., (°F)

t_A = Air Temp., (°F)

R_o = Heat Transfer Resistance, $\frac{(\text{hr})(\text{ft})(°\text{F})}{\text{Btu}}$

The overall heat transfer resistance (R_o) can be subdivided into the following individual resistances:

R_{pw} = Pipe wall resistance

R_s = Soil resistance

R_{SA} = Soil-air interface resistance

The pipe wall resistance, R_{pw}, is calculated from the equation:

$$R_{pw} = \frac{X}{K\,A_L}$$

where:

X = Wall thickness, (ft)

A_L = Log Mean Area of Pipe Wall, (ft^2)

K = Thermal conductivity of pipe wall, $\frac{(\text{Btu})(\text{ft})}{(\text{ft}^2)(\text{hr})(°\text{F})}$

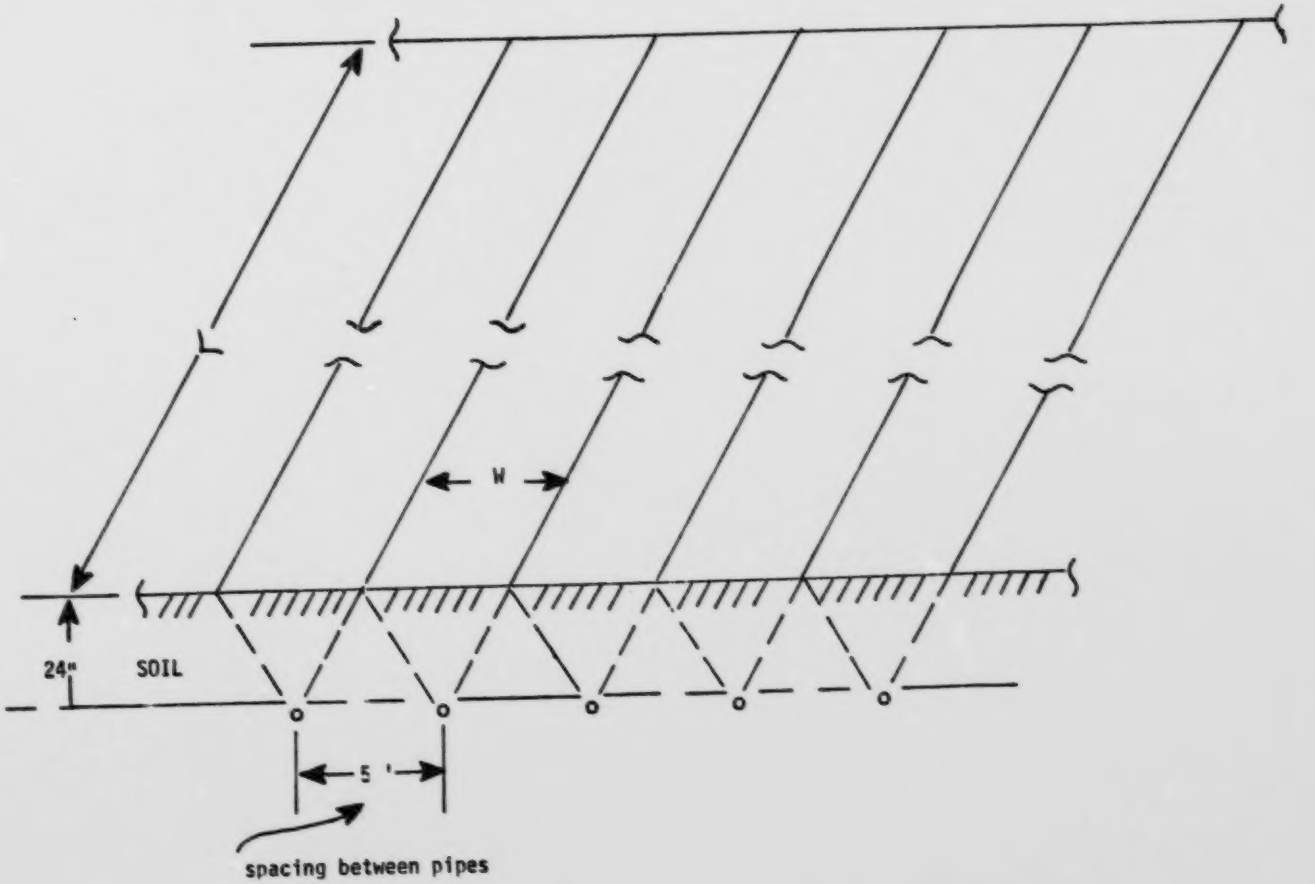
W
24"
SOIL
5 '
spacing between pipes

Figure 42. Undersoil pipe grid.

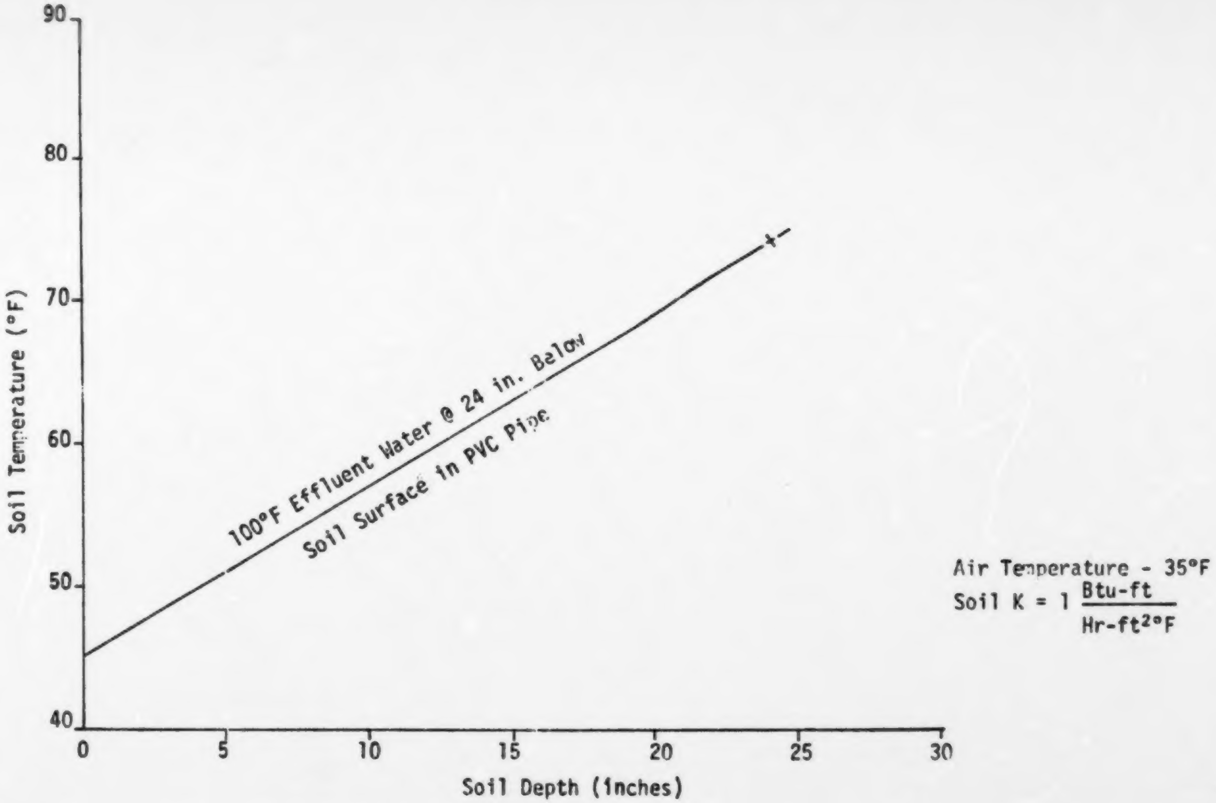

Figure 43. Soil temperature vs. soil depth.

The resistance of the soil, R_s, is calculated from the following equation for a horizontal cylinder of length L (ft) and diameter D (ft) with axis at distance Z (ft) below the surface:

$$R_s = \frac{1}{2\pi LK} \ln \left(\frac{4Z}{D}\right)$$

$$k = \text{Thermal conductivity of soil} - \frac{\text{Btu ft}}{\text{ft}^2 \text{ hr } ^\circ\text{F}}$$

The soil-air heat transfer resistance is inversely related to the sum of the natural convection film coefficient (h_c) and the radiation coefficient (h_r) multiplied by the Area (A_{SA}) of the soil-air interface.

$$R_{SA} = \frac{1}{(h_c + h_r)\, A_{SA}}$$

where:

$$R_{SA} = \frac{^\circ\text{F hr-ft}}{\text{Btu}}$$

$$h_c \;\&\; h_r = \frac{\text{Btu}}{\text{hr ft}^2 \; ^\circ\text{F}}$$

$$A_{SA} = \text{ft}^2$$

The area (A_{SA}) is equal to the surface area of the heated plot, that is the length (L) and width of the soil air interface.

The natural convection film coefficient (h_c) is calculated from the following relationship:

$$h_c = 0.27\,(t/L)^{0.25}$$

where:

t = differential temperature between soil and air - °F

The radiation coefficient (h_r) is calculated from the following relationship:

$$h_r = \frac{0.173\ e_1 \left[\frac{(T_{SA})^4}{100} - \frac{(T_A)^4}{100}\right]}{T_{SA} - T_A}$$

e_1 = Emmissivity of the soil surface at T_1

T_{SA} = Absolute temperature of soil surface in °R

T_A = Absolute temperature of air °R

Sizing of pipe within the grid must be determined within these parameters: seed germination occurring at 53 to 59°F, pipe carrying 100°F water, and pipe burial 24 in. below soil surface.

Assuming a soil-air interface temperature (t_{SA}), the heat flux was calculated. The calculated heat flux was then substituted in the following two equations to prove the assumption:

$$q = \frac{100 - t_{SA}}{R_S} \qquad q = \frac{t_{SA} - 35}{R_{SA}}$$

The temperature of the soil vs depth and their relationship to effluent water temperature is shown on Figure 43.

Utilizing a 2-1/2 in. diameter pipe (Figure 44) grid system with parallel pipes spaced at 5 ft centers (Figure 45) containing 100°F effluent water, the soil-air interface temperature would be 45°F (Figure 46). The soil-air interface temperature, however, between and above the pipes would be 44°F.

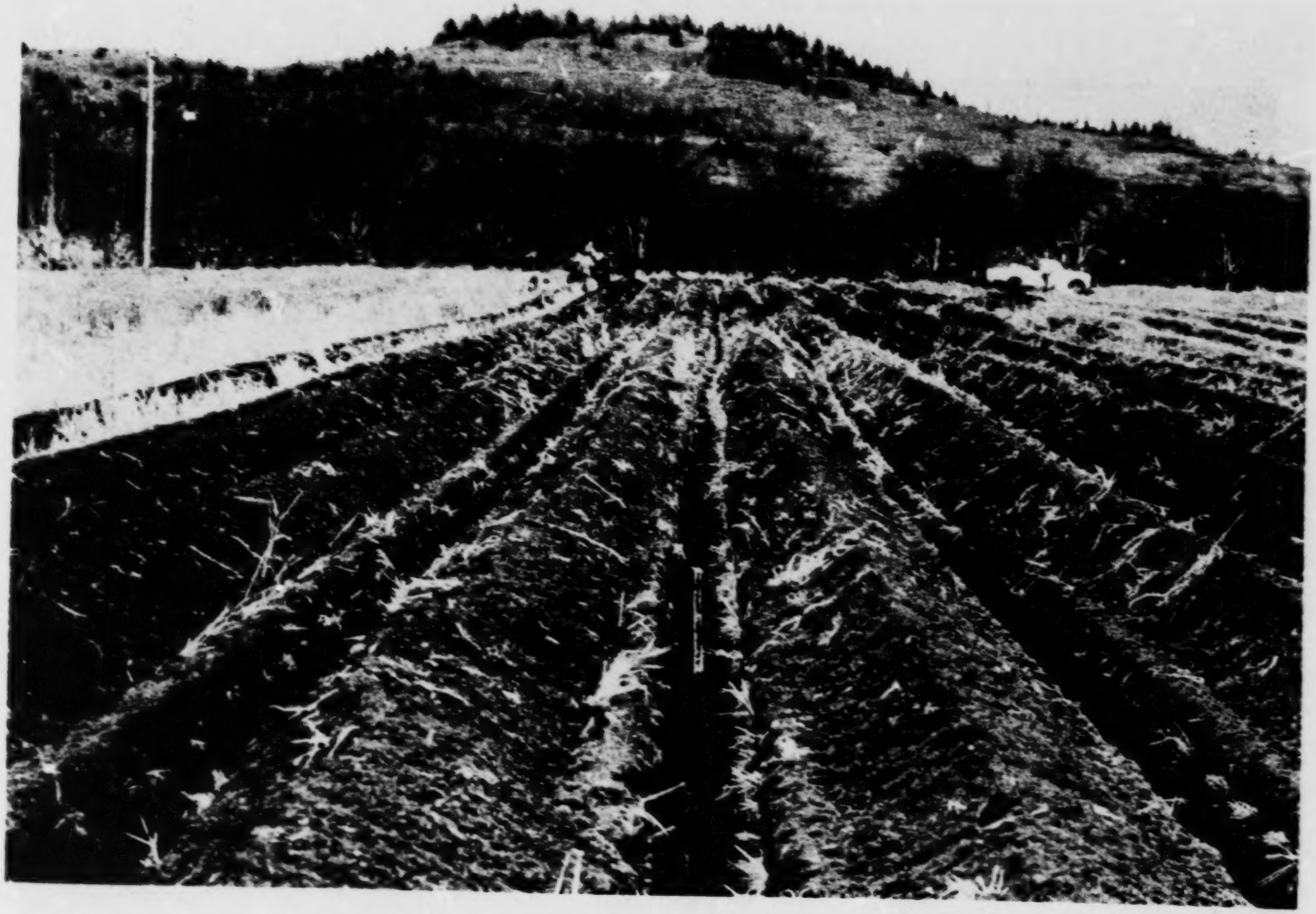

Figure 44. Grid layout for soil heating study

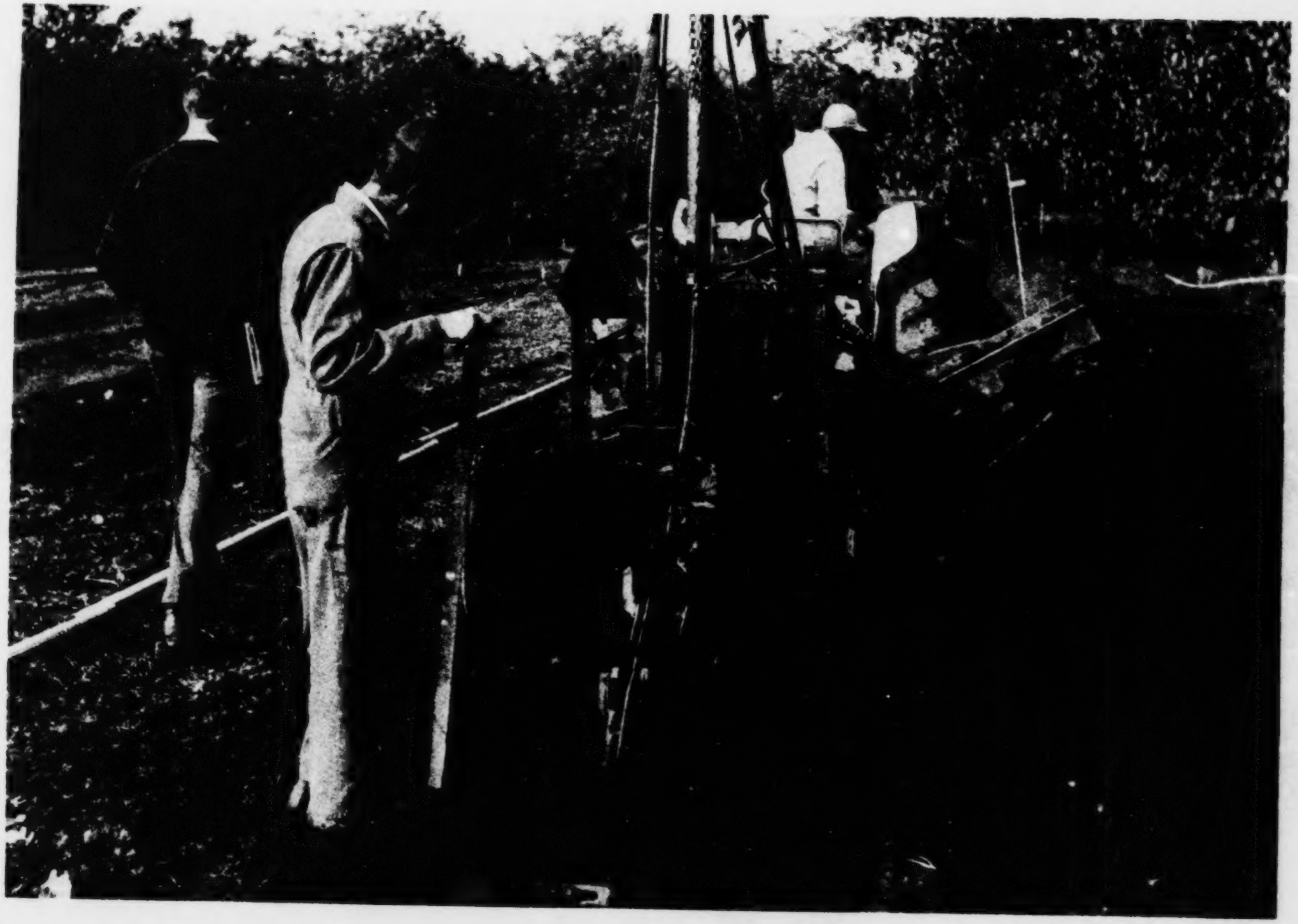

Figure 45. Installation of underground pipe grid system for soil warming study

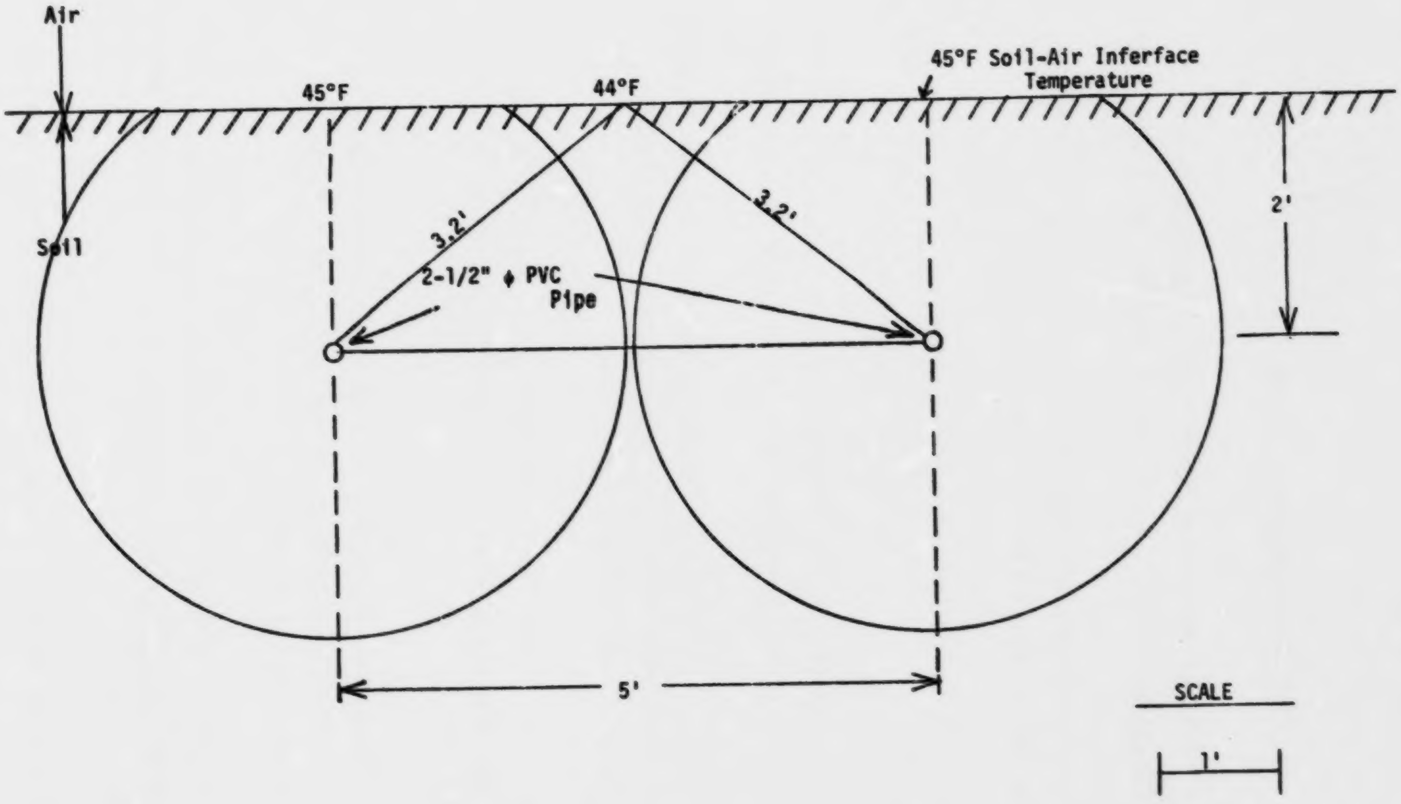
Air
Soil
45°F
44°F
45°F Soil-Air Inferface Temperature
3.2'
3.2'
2-1/2" ϕ PVC Pipe
2'
5'
SCALE
1'

Figure 46. Soil-Air Interface Temperature Variation. 100°F effluent water in PVC pipe.

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5. J. Bornstein, et al. "Insulated Soil-Heating System to Prevent Forest Heaving of Field Instrumentation," *Journal of Agricultural Engineering Research*, Vol. 14, pp. 100-103. May 1969.

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8. D. K. Cassel. "Soil-Water Movement in Response to Imposed Temperature Gradients," *Proceedings of the Soil Science Society*, Vol. 33, pp. 493-500. July 1969.

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13. J. R. Gingrich. "Low Cost Method for Maintaining Constant Soil Temperatures in the Greenhouse," Agronomy Journal. Vol. 57, pp. 316-317. May 1965.

14. A. R. Mack and W. A. Evans. "Soil Temperature Control Systems for Field Plots," Canadian Journal of Soil Science, Vol. 45, pp. 105-7. February 1965.

15. A. W. Dimock. "A Soil Temperature System Employing Air as the Heat-Transfer Medium" Plant Disease Reporter. Vol. 51, No. 10, pp. 873-76.

GENERAL PROCEDURE

The thermal water soil heating system was completed and installed in early May 1971. Figure 47 is a schematic of the project site and shows the locations of the two blocks of heated soil. The smaller heated block was 510 ft x 60 ft. A small adjacent area served as a check block. The large heated block was 120 ft x 470 ft with a 60 ft x 470 ft plot on the north and south of the heated block reserved for control plots. The system consisted of a grid work of 2-1/2 in. diameter black polyvinylchloride (PVC) pipe buried about 26 in. deep and 60 in. centers (Figure 47). The PVC pipes of the larger block were connected to a 6 in. diameter steel inlet and outlet manifold; PVC pipes of the smaller heated block were connected to 4 in. diameter steel inlet and outlet manifolds. About 350 and 100 gpm of thermal water were pumped through the large and small blocks, respectively. All heater soil temperatures referred to in this report were from the large heated block.

Although the soil heat grids were completed for the 1971 growing season, there was no thermal water because of a labor strike at the Weyerhaeuser plant that started in the spring and lasted through mid-summer. Thus, the first data on soil temperatures and crop responses were collected in 1972.

Platinum bulb temperature sensors connected to chart-type recorders were placed in tomato rows on black plastic mulched and non-mulched plots split between heated and non-heated soil during the 1972 growing season. Temperature sensors on heated soil were placed at 1, 6, 12, and 24 in. depths in a vertical line above and halfway between buried heat pipes (Figure 48). Temperature probes were also placed in non-heated control plots at 1, 6, 12, and 24 in. depths.

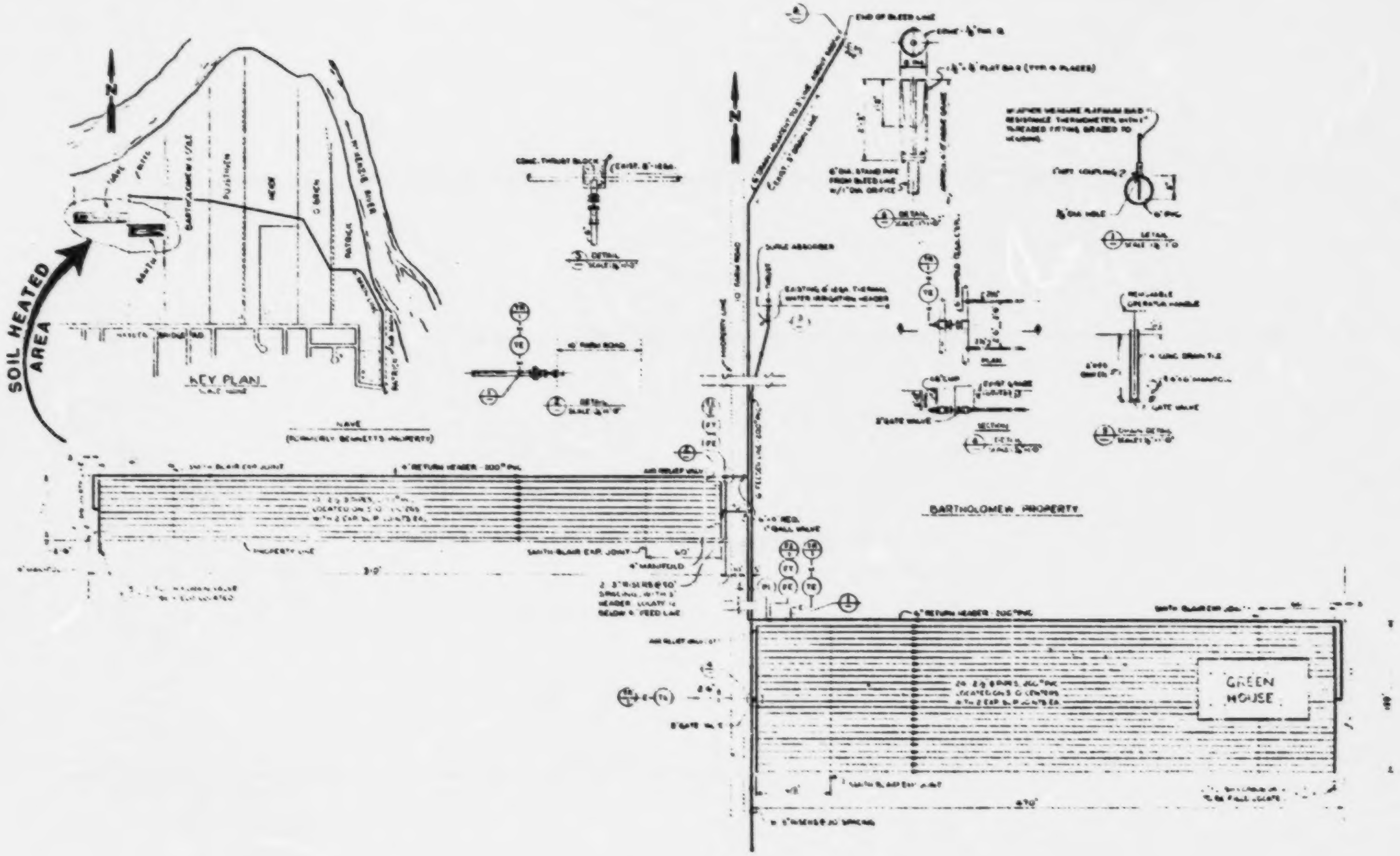
SOIL HEATED AREA
KEY PLAN
N
N
BARTHOLOMEW PROPERTY
GREEN HOUSE

Figure 47. Undersoil heating with greenhouse location -- plot plan and details

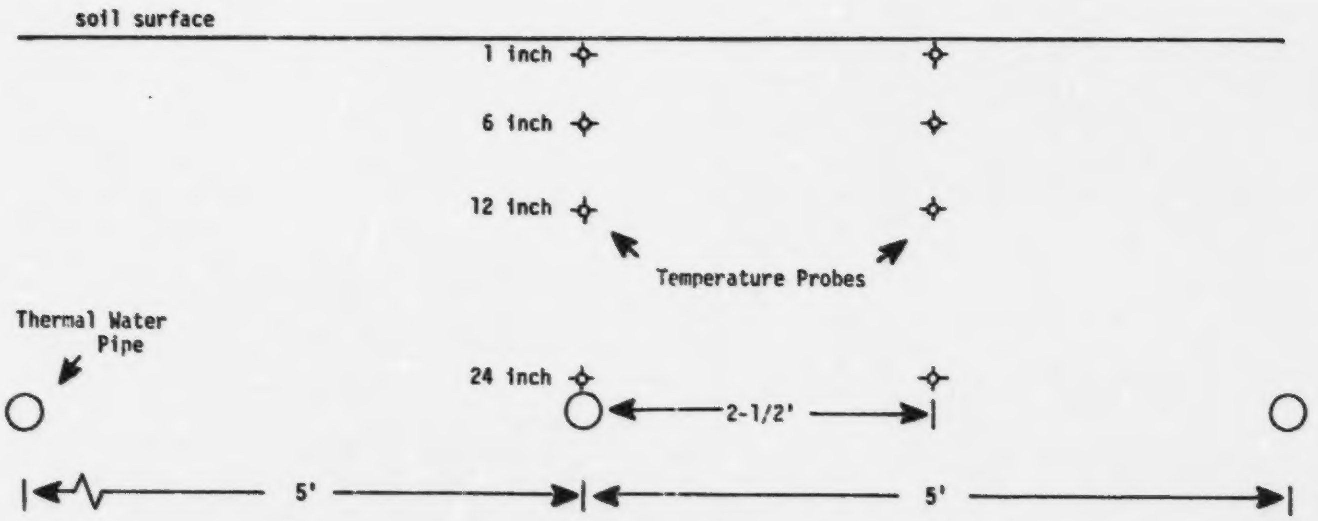
soil surface
1 inch
6 inch
12 inch
Temperature Probes
Thermal Water Pipe
24 inch
2-1/2'
5'
5'

Figure 48. Placement of temperature sensors in relationship to buried thermal water heat lines and soil surface.

RECORDED SOIL TEMPERATURES

Soil temperatures are influenced by changing solar load and related air temperatures. Temperatures of non-heated soil at 6, 12, and 24 in. are shown in Figure 49. As would be expected, 6 in. depth temperatures averaged somewhat warmer than 12 and 24 in. depth temperatures during mid-summer and averaged cooler than 12 and 24 in. depths during the remainder of the year. Although it is not shown in Figure 49, the diurnal temperature fluctuation at the 6 in. depth was greater than at the deeper recorded levels.

During June, July, August, and the first part of September 1972, soil temperatures at the 1 in. depth were not influenced by the thermal water grid. During the spring, fall, and winter months, mean weekly 1 in. depth soil temperatures of the heated area ranged from .5 to about 4°F warmer than non-heated soil.

Temperatures at the 6, 12, and 24 in. depths were modified by the thermal water circulated through the buried soil heat grid, but temperatures were not uniform for any given depth in a horizontal line across the soil heat grid. Soil farthest from the pipes at any given depth was cooler than soil closer to the heat lines. The coolest soil at any given depth in the heated blocks was mid-way between the heat lines that were buried on 5 ft centers (Figure 48). As was the case with non-heated soil, temperatures of heated soil were warmer during mid-summer than during the rest of the year.

The warmest 6 in. depth soil temperature, recorded in a vertical line above the buried heat line, averaged 4.8°F warmer than unheated 6 in. depth soil temperature for January 1972 through March 1973 (Figure 50). The coolest 6 in. depth soil temperatures recorded mid-way between buried heat lines in the heated area averaged 2.8°F warmer than the unheated 6 in. depth soil temperature for the same period of time (Figure 50). During the warmest part of the growing season from June 22

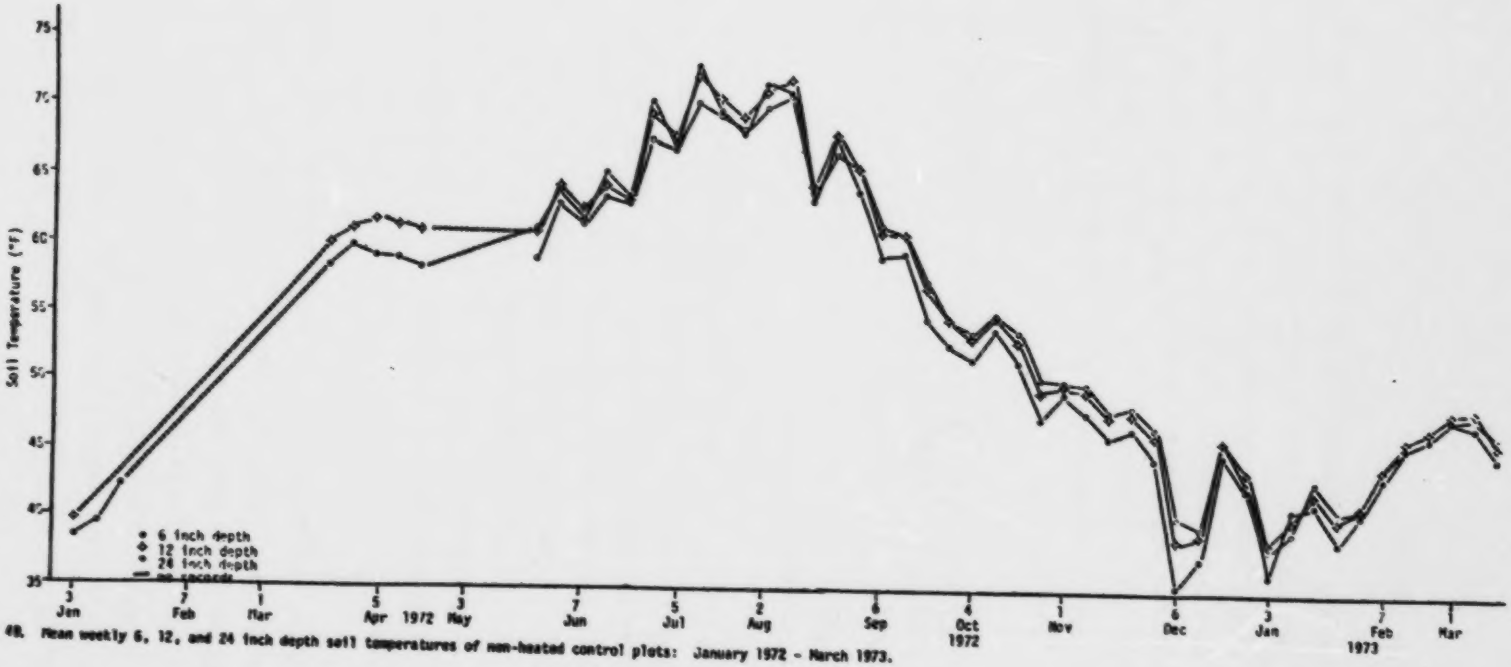

Figure 48. Mean weekly 6, 12, and 24 inch depth soil temperatures of non-heated control plots: January 1972 - March 1973.

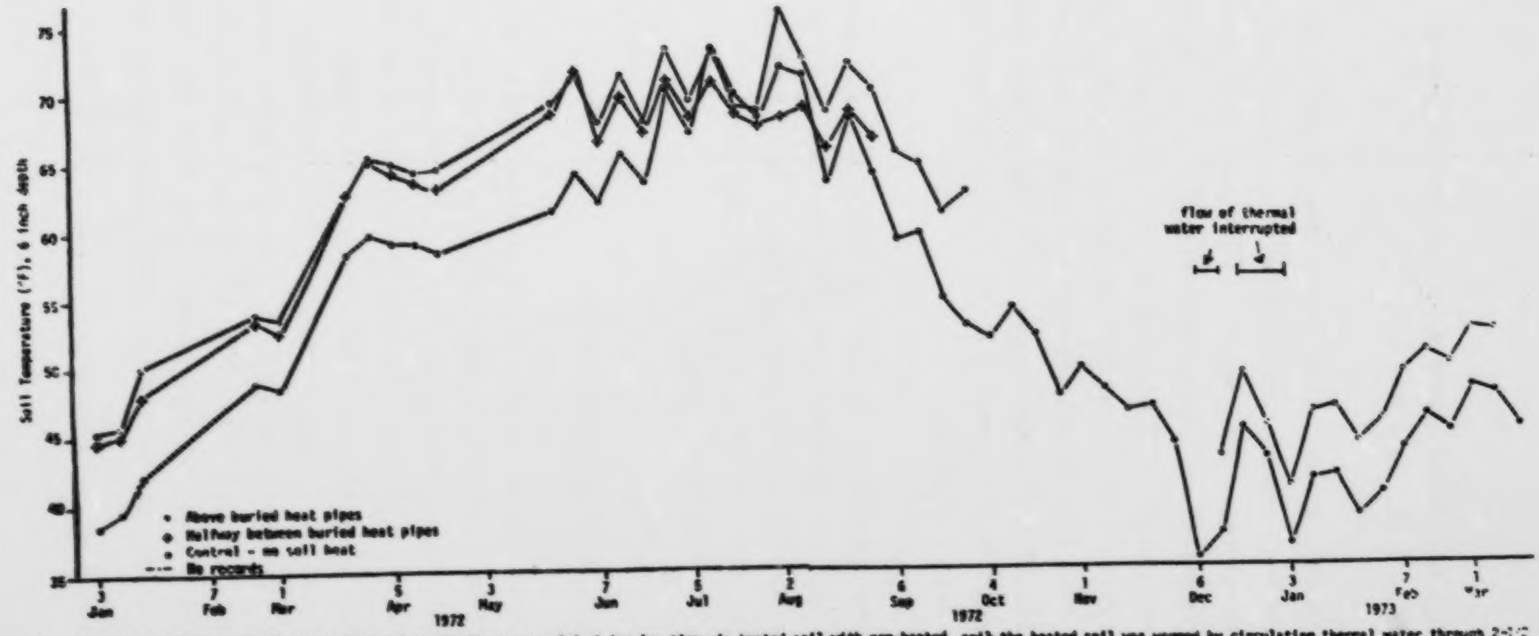

Figure 50. Comparison of mean weekly 6 inch depth soil temperatures recorded at two locations in heated soil with non-heated soil; the heated soil was warmed by circulating thermal water through 2-1/2 inch diameter plastic pipe buried 26 inches and spaced 5 ft apart.

through August 9, there was little temperature difference between heated and non-heated soil at the 6 in. depth.

Temperatures of heated soil at the 12 in. depth were closer to those of heat lines, and heated soil temperatures were modified relatively more than 6 in. depth temperatures. The greatest temperature difference between 12 in. depth non-heated and heated soil averaged 7.8°F for the recorded periods between January 1972 and March 1973 (Figure 51); the least difference averaged 3.4°F. From June 28 through August 2, 1972, there was little difference in non-heated soil and the coolest soil in the heated block at the 12 in. depth (Figure 51). The warmest soil in the heated block averaged 6.7°F warmer than non-heated soil during the same June 28 through August 2 period.

The greatest difference between heated and non-heated soil occurred at the 24 in. depth, closest to the heat lines that were buried at about 26 in. The average temperature difference at 24 in. depth between the coolest soil in the heated block at a 24 in. depth and the 24 in. depth in the non-heated soil was 8.4°F (Figure 52).

THE INFLUENCE OF SOIL HEAT ON SELECTED PLANTS

Although it is known that yields of rice and greenhouse crops are affected by low root zone temperature, little is known about the effect of soil temperature on production of most crops. Low temperature irrigation water that in turn cools the soil is considered to be an important limiting factor in Japanese rice production, and when cold water from Shasta Dam was first used to irrigate rice in northern California, the rice would not mature in time for harvest.[28] When cold water irrigation caused soil temperature to drop below 59°F, greenhouse cucumber plants ceased to grow and were damaged.[29] Soil temperature lower than optimum for crops of tropical origin may well occur in the field during the growing season.

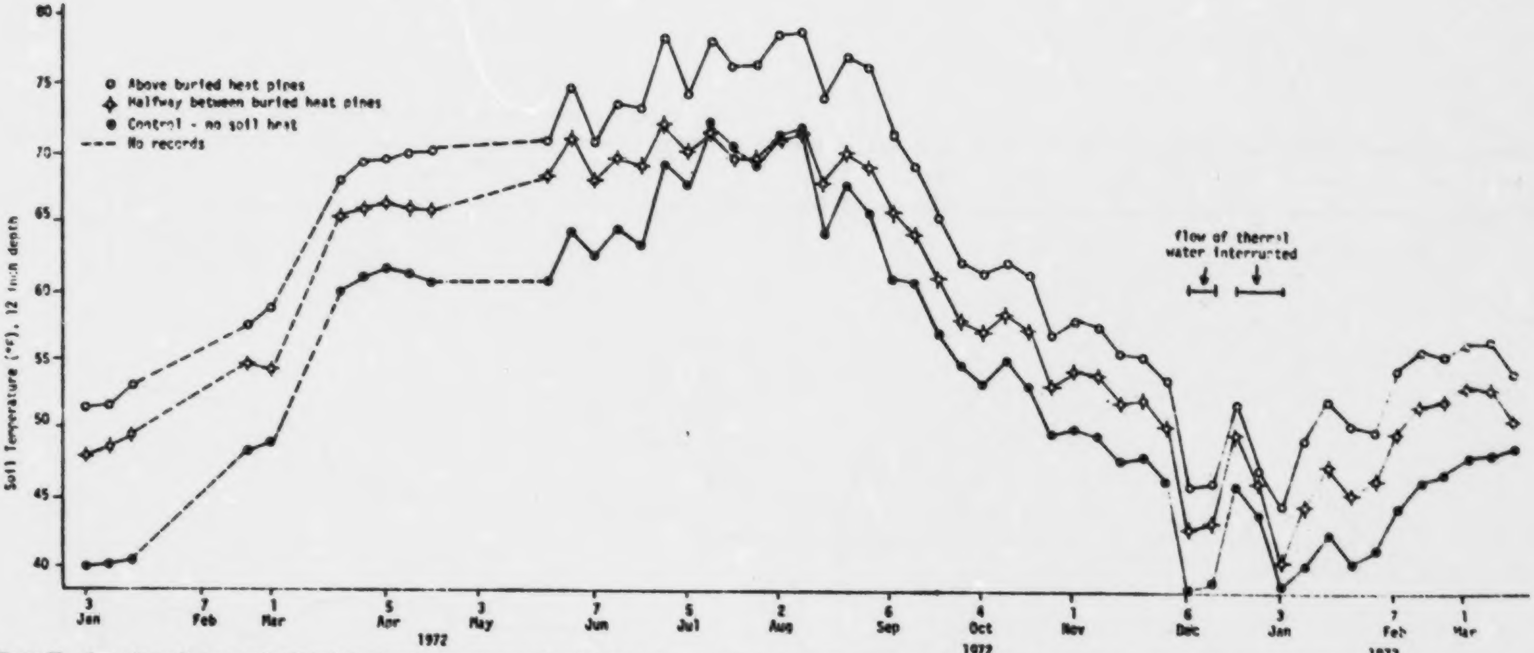

Figure 51. Comparison of mean weekly 12 inch depth soil temperatures recorded at two locations in heated soil with non-heated soil: the heated soil was warmed by circulating thermal water through 2-1/2 inch diameter plastic pipes buried 26 inches and spaced 5 ft apart.

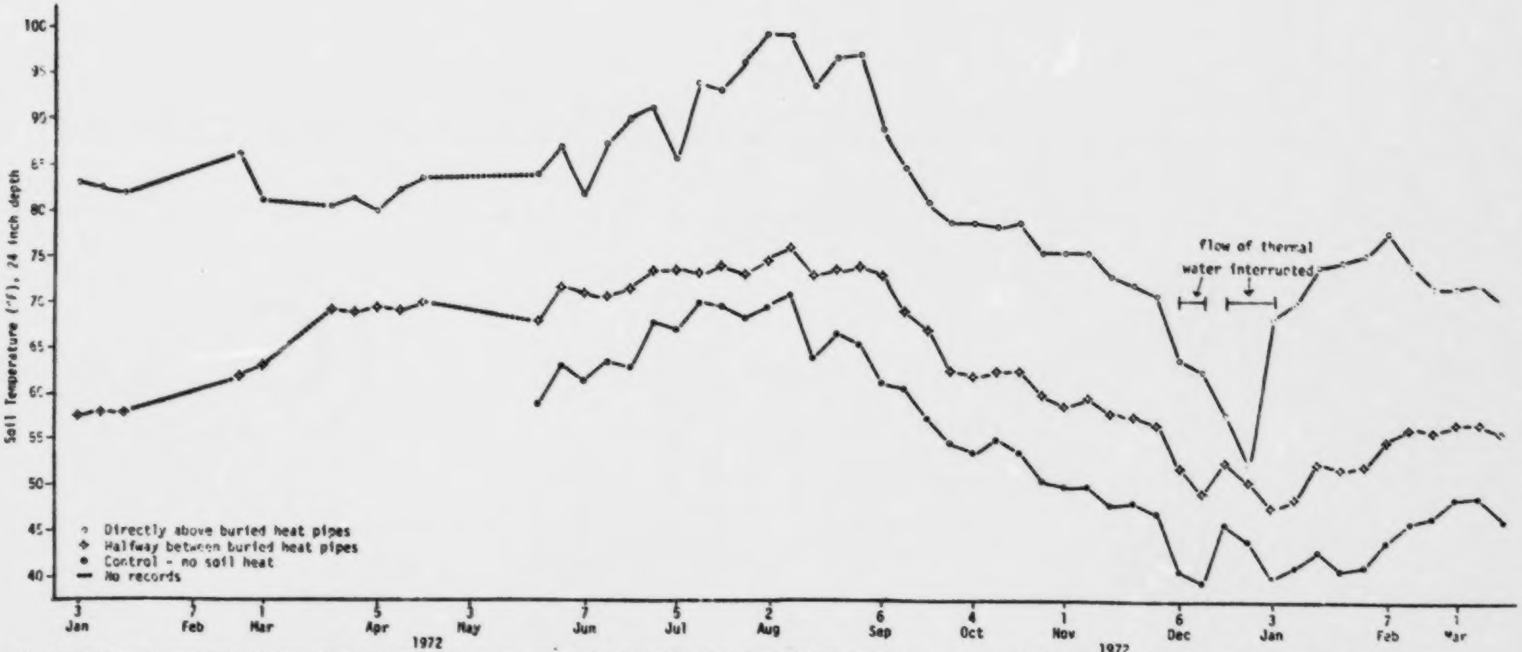

Figure 52. Comparison of mean weekly 24 inch depth soil temperatures recorded at two locations in heated soil with non-heated soil: the heated soil was warmed by circulating thermal water through 2-1/2 inch diameter plastic pipes buried 26 inches and spaced 5 ft apart.

Small changes in soil temperature can cause large differences in growth of many woody plants, and the roots of these plants may function only in a narrow range of soil temperatures.[30] For example, *Lonicera* cv. Zabel and *Weigela* cv. Ferrie produce good root growth over a wide range of temperature (54-90°F), while *Physocarpus opulifolius* v. *nanus* and *Ribes alpinum* had narrower optimum soil temperature ranges, 62.5-79°F and 66-80.5°F, respectively.[31] Although plant shoots depend upon roots for water and nutrients, the same soil temperature may affect the development of shoots and roots differently. Generally, soil temperatures that produce the most shoot growth are higher than soil temperatures needed to produce the greatest root growth.[31] Roots produced at relatively low soil temperatures were whiter, more succulent, thicker, and had fewer lateral roots than roots produced at relatively higher temperatures.

Water use by plants is also influenced by soil temperature. Generally, the use of water increases as the soil temperature increases.[31]

The detailed effects of soil temperature on plant growth and development probably can be determined only in controlled experiments where specific plant shoot and root conditions are maintained. Any field studies with soil heat are complicated by: 1) variable field conditions, 2) changing environmental factors that influence soil temperature throughout a growing season, and 3) soil temperature variations through the root zone.

Another complicating factor is that crops in these studies had different genetic backgrounds and indigenous habitats and probably did not require the same root temperature for optimum growth. Also, when a commercial source of thermal water is used, the temperature will probably fluctuate (Figure 3) and will not be under complete control of the agriculturist.

Therefore, the results of these studies with the selected crops reflect all of the above variables. When detailed information becomes available on optimum root zone temperature for different crops, some facet of these studies might be changed to alter results for individual crops.

The greatest variation in soil temperature within the heated block itself also occurred at the 24 in. depth where the warmest soil averaged 17.4°F warmer than the coolest soil (Figure 52). At depths closer to the soil surface and further from the heat lines, temperature variations were less in a horizontal line than at the 24 in. depth. Temperature differences between warmest and coolest heated soil at 12 and 6 in. depth averaged 4.3 and 1.6°F, respectively (Figures 51 and 50). Generally, the greatest soil temperature variation at any given depth in the heated block occurred during the cooler months and the least variation occurred during the summer months.

The mean weekly temperatures depicted in Figures 50, 51, and 52 for heated soil are the products of solar input, related ambient air temperature, other less well defined environmental factors, and the temperature of thermal water passed through the soil heat grid.

As can be seen in the various Figures, no constant soil or air temperatures were maintained. The thermal water was used as it was supplied and probably represents a realistic view of what might be expected with a larger installation that relied on industrial waste thermal water. Any crop responses to soil heat that are discussed later in this section were modified or not modified by the sum total of heat differences shown in Figures 50, 51, and 52.

Although no actual measurement of temperature drop across the wall of buried PVC pipe were made, temperature sensors were placed about 1-1/2 to 2 in. directly above the heat lines. An average of 13.2°F temperature drop occurred between the thermal water as it entered the buried pipes and the temperature recorded about 1-1/2 to 2 in. from the outside of the pipe (Figure 53). This temperature drop was greater from July 12 through September 6 than during late September through November (Fig. 53).

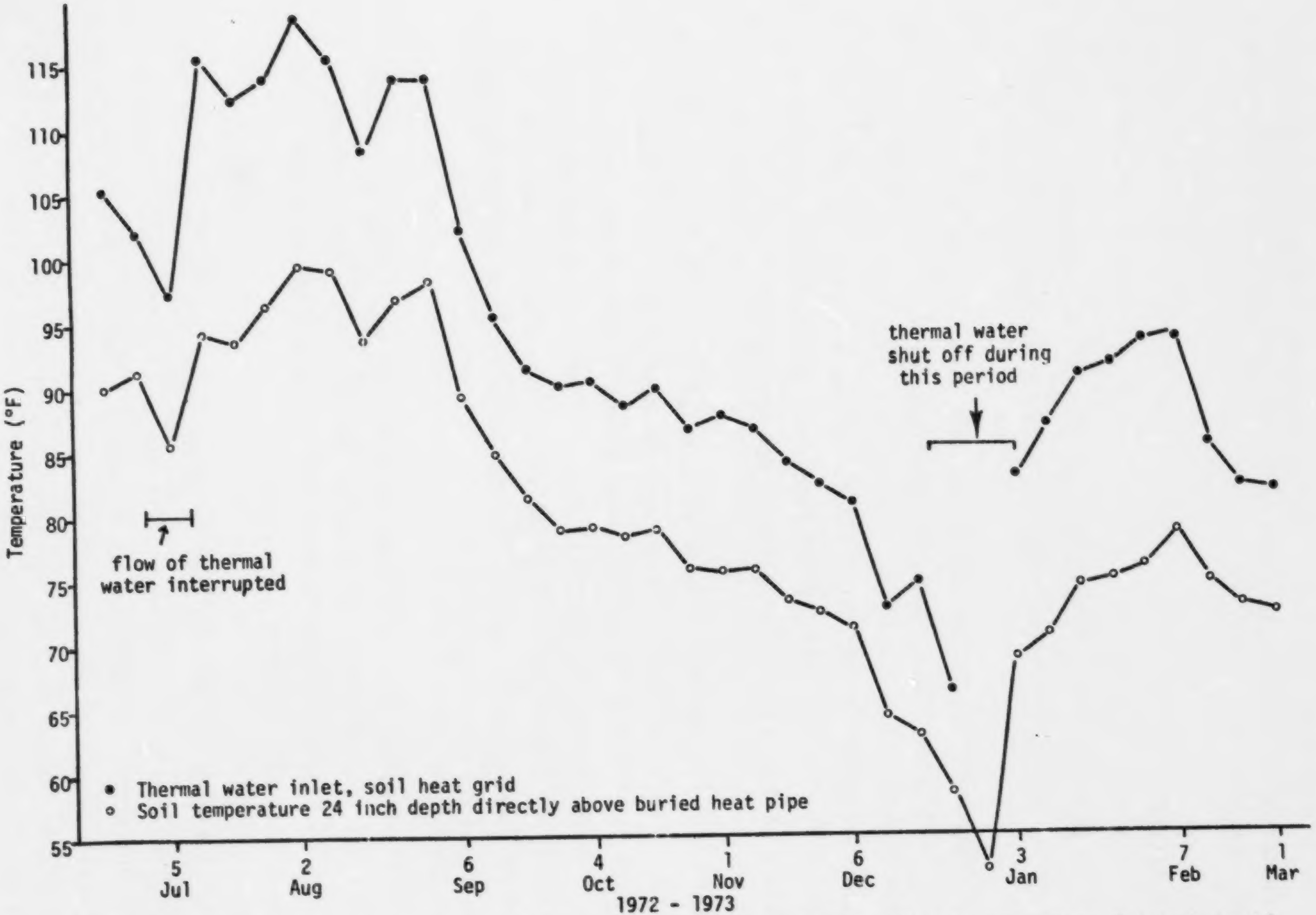

Figure 53 . Comparison of thermal water temperature at inlet to soil heat grid with soil temperature (24 inch depth) about 2 inches above thermal water heat pipe.

The greater temperature drop during mid-summer probably was due to a reduction in soil moisture around the pipes, resulting in reduced heat transfer.

Tomatoes

Procedure--Fertilizer (1000 lb 10-20-20/acre) was broadcast and incorporated with a rototiller into the area for tomatoes on May 4, 1972.

Thermal water heated and non-heated soil were compared as main plots and replicated twice. Sub-plots consisted of 4 mil black plastic film mulched and non-mulched rows. Tomato cvs. Fire ball and Willamette were transplanted into the field during May 9 through 11, 1972, on 2 x 4 ft spacings. Each plant received 1 pt of 9-45-15 fertilizer mixed at the rate of 1 oz material per gal water.

Delmhorst soil moisture blocks were installed in black plastic mulched and non-mulched plots on heated and non-heated soil during June 1972. Moisture blocks on heated soil were placed in tomato rows at 6, 12, 24, and 30 in. depths in a vertical line with and halfway between buried heat pipes (Figure 54). Moisture blocks were placed at the same depths in non-heated control plots. Thermal water applied through sprinklers was used for all irrigations.

The first mature leaf down from the plant tip was taken for nutrient analyses from 12 plants per plot on June 22, 1972. Tomato plants were in early bloom. Chemical composition was determined by Oregon State University Soil Analyses Laboratory.

The herbicide "Enide" was applied at the rate of 6 lbs active per acre on June 28. "Diazinon" insecticide was applied to tomato foliage at .25 lbs active per acre for aphid control. "Sevin" insecticide was applied on July 25 and August 2 at rate of 1 lb active per acre. The fungicide "Maneb" at 3 lbs per acre was applied on August 2 and 26, 1972, to check Early Blight development.

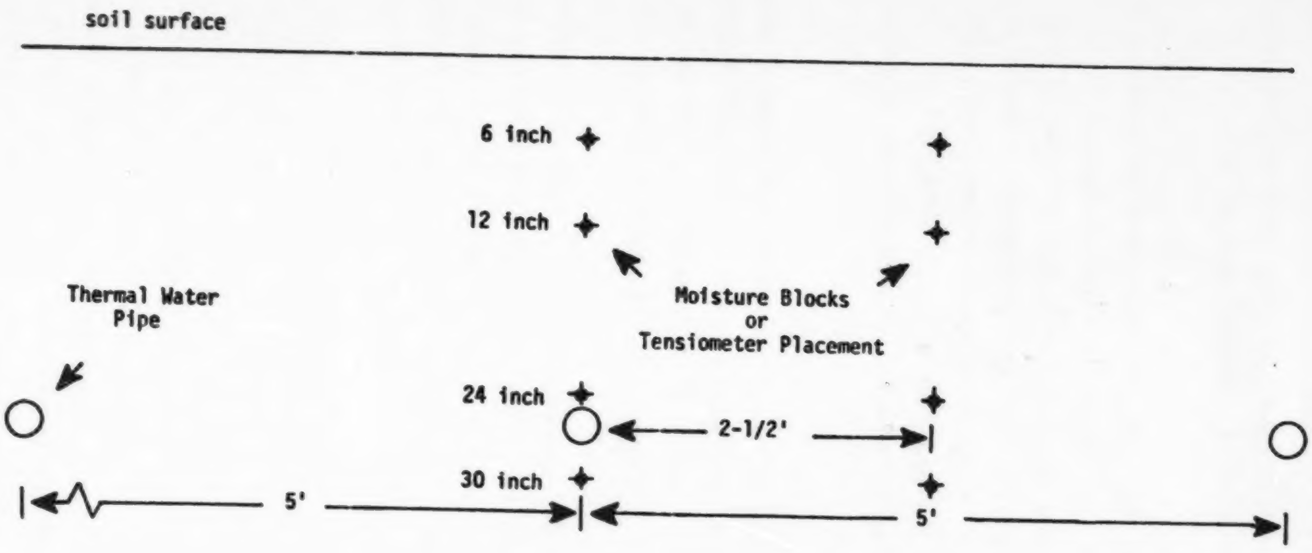
soil surface
6 inch
12 inch
24 inch
30 inch
Thermal Water Pipe
Moisture Blocks or Tensiometer Placement
2-1/2'
5'
5'

Figure 54. Placement of soil moisture sensors in relationship to buried thermal water heat lines and soil surface.

The middle 20 ft of each plot were harvested four times between August 26 and October 20, 1972. Fruit from each plot were weighed, counted, and classed as U.S. No. 1 and No. 2 canning[32] and culls.

Results and Discussion--The nutrient level data for tomatoes were not statistically analyzed, but plants from soil heated plots tended to have more N, P, K, Ca, Mg, and Zn than plants from non-heated plots (Table 7). Mn was the exception; plants from soil heated plots tended to have less Mn than control plants. In general, these trends are in agreement with other findings.[33-37] The lower Mn in plants from soil heated plots is in contrast to studies with strawberries[38] where Mn was decreased by lower soil temperature.

Soil heat did not influence tomato yields in this study (Table 8). Black plastic mulch increased yield of No. 1 'Fireball' fruit, but did not significantly affect yield of 'Willamette.' There was no interaction between the plastic mulch and soil heat or control plots.

Although soil heating has increased tomato yields by 50 percent,[39] yield of 'Fireball' and 'Willamette' tomatoes was not increased by soil heating during 1972 in this trial. Differences in location of test sites, growing seasons, time of planting, and type and placement of soil heating equipment probably contributed to lack of yield response at the project site in 1972.

Sweet Corn

Procedure--The area for sweet corn was fertilized with 96 lb N and 130 lb P per acre in 1 ft wide bands spaced on 4 ft centers on June 1972. The fertilizers were incorporated into the soil with a rototiller. Sweet corn cv. Jubilee was seeded with a Planet Jr. planter into the fertilized bands on June 13, 1972. In-row spacing of plants averaged about 10 in. apart. Rows were 4 ft apart.

Table 7. NUTRIENT LEVELS (DRY WT BASIS) IN TOMATO LEAVES OF 'FIREBALL' AND 'WILLAMETTE' FROM SOIL HEATED AND CONTROL PLOTS

Treatment	Nutrient Level - Dry Wt Basis Total N, %	P, %	K, %	Ca, %	Mg, %	Zn, ppm	Mn, ppm
Fireball:							
Soil heat	4.59	0.57	3.78	0.43	0.96	37.5	59.0
Control	4.56	0.51	3.62	0.41	0.94	33.0	75.7
Willamette:							
Soil heat	4.70	0.65	4.13	0.39	0.82	42.0	55.5
Control	4.61	0.58	4.01	0.33	0.80	34.5	65.5

Table 8. EFFECTS OF SOIL HEAT AND BLACK PLASTIC 4-MIL FILM MULCH ON YIELD OF 'FIREBALL' AND 'WILLAMETTE' TOMATOES[z]

	U.S. Canning Grades					
	No. 1		No. 2		Cull and rotten fruit	
	Tons/Acre	Avg. fruit wt, lbs	Tons/Acre	Avg. fruit wt, lbs	Tons/Acre	Avg. fruit wt, lbs
Fireball						
Soil heat	39.7	.22	13.7	.21	16.0	.20
Control	42.3	.24	13.7	.23	14.0	.21
Mulch	46.4a	.23	13.9	.21	14.4	.20
No-mulch	35.7b	.24	13.6	.23	15.6	.21
Willamette						
Soil heat	57.5	.33	12.5	.32	18.8	.27
Control	55.2	.31	10.4	.30	17.9	.24
Mulch	52.9	.32	11.2	.32	19.6	.26
No-mulch	59.8	.32	11.7	.30	17.2	.24

[z] Means within a column in each series followed by different letters differ significantly at 5% level.

'Jubilee' was planted in soil heated and non-heated blocks (2 rows per plot, 30 ft long) and replicated four times. Thermal water applied through sprinklers was used for all irrigations.

Leaf samples were taken from corn plants that had just started to produce tassels in each plot on August 16, 1972. Samples consisted of leaf sections about 10 in. long taken from the mid-section of middle aged leaves. The samples from Replications 1 and 2 were combined and 3 and 4 were combined before they were analyzed for P, K, Ca, Mg, Zn, Mn, and total N by Oregon State University's soil testing laboratory.

The number of immature ears less than 3 in. in length and ears between 3 and 6 in. long were counted on August 21, 1972, to determine if soil heat hastened early development.

Corn plots were harvested September 18 through 20, 1972. The fresh weight and number of ungraded, graded, and immature ears were recorded. Plant height and weight also were recorded.

A 20 ft section of row was harvested from the center of each plot September 18 through 20, 1972. Fresh plant and ear weights were recorded and ears were husked and graded (Table 9.)

Results and Discussion--Nutrient uptake trends for selected elements are shown in Table 10. Only two samples were analyzed per treatment for each element, so the data was not statistically analyzed. However, the results are similar to other findings. Less N was taken up by corn on cooler control soil than on heated soil (Table 10). N levels in shoots have been reported to decrease as root temperature decreases in chrysanthemums[33] and strawberries.[40] The lower P levels associated with the lower soil temperature control plots parallel findings of Knoll[35] on corn. K and Ca uptake was not altered much by soil heat. Mg in corn has been observed to increase with warmer soil temperatures[37] and was increased by soil heating. Zn uptake was not influenced by soil heat, but Mn uptake was increased by soil heat as occurred with chrysanthemums.[33]

Table 9. YIELD OF SWEET CORN, CV. JUBILEE, HARVESTED SEPTEMBER 18 THROUGH 20, 1972, FROM THERMAL WATER HEATED AND NON-HEATED SOIL[z]

	Ungraded ears with husks		Graded ears minus husks		Immature ears		Plant wt. minus ears	Average plant
	Doz./A	Tons/A	Doz./A	Tons/A	Doz./A	Tons/A	Tons/A	Height-ft
Soil heat	1,859a	7.4a	1,473a	5.0a	387a	0.3a	3.4a	8.8a
Control	1,368b	5.8b	1,196b	3.9b	169b	0.2a	3.5a	8.4a

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[z] Within one vertical column, values followed by different letters differ at the 5% level.

Table 10. NUTRIENT LEVELS (DRY WT BASIS) IN LEAVES OF SWEET CORN FROM SOIL HEATED AND CONTROL PLOTS

	Nutrient Level-Dry Wt Basis						
Treatment	Total-N, %	P, %	K, %	Ca, %	Mg, %	Zn, ppm	Mn, ppm
Soil heat	3.52	0.42	2.68	0.08	0.33	41.5	77.5
Control	3.33	0.32	2.57	0.07	0.25	42.0	61.5

Sweet corn on heated soil was visually larger than on non-heated soil on July 20, 1972 (Figure 55), and early ear development was stimulated by soil heat (Table 11). The soil heated plots averaged 72 percent more ears between 3 and 6 in. than control plots on August 21, 1972. There was no difference in the number of ears less than 3 in. between soil heated and control plots.

At harvest, the weight of ungraded, graded, and immature ears was increased by 28, 35, and 50 percent, respectively, compared to production from control plots (Table 9). On a number basis, ungraded, graded, and immature ears were increased by 36, 23, and 129 percent by heated soil when compared to control plot production.

Overall, soil heated plots produced more but slightly smaller ears (.66 lb per ear from soil heat vs .70 lb per ear from control) than the controls. There also was little difference in average ear weight of graded ears from soil heated and control plots (.56 lb per ear from soil heat vs .54 lb per ear from control).

More immature ears were formed on heated soil than on control plots but the ears did not develop, and there was little difference in weight of immature ears at harvest (Table 9).

Most of the difference in size of corn plants between soil heated and control blocks that was noted in July (Figure 55) was not apparent at harvest. There was little difference in average height and weight of plants from heated and control plots on September 20, 1972 (Table 9).

Asparagus Crown Planting

Procedure--Fertilizer was broadcast at the rate of 300 lb 16-20-0, 88 lb P, and 40 lb K per acre on the area for asparagus crowns. "Diazinon" insecticide was applied at the rate of 9.8 lb active material per acre for Symphlan and wire-worm control. Fertilizers and insecticide were rototilled into the soil.

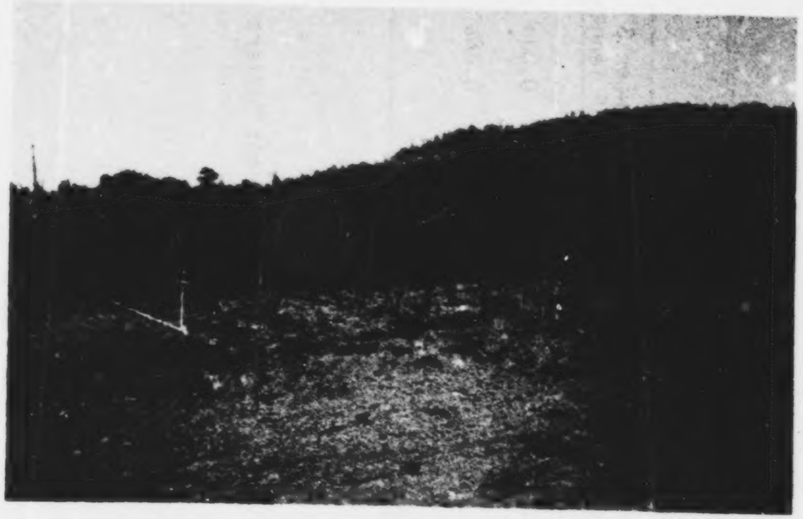
Soil Heat
↑
Control

Figure 55: Sweet corn 'Jubilee' growing on soil heated by thermal water and on non-heated soil--July 20, 1972.

Table 11. EFFECT OF SOIL HEAT ON EARLY SWEET CORN EAR DEVELOPMENT, CV. JUBILEE; SAMPLES TAKEN AUGUST 21, 1972

Treatment	Average Number of Ears/Plant Total ears per plant	 Less than 3" length	 Between 3" and 6" length
Soil Heat	1.09a	0.26a	0.83a
Control	0.70b	0.21a	0.48b

Within one vertical column, values followed by different letters differ at the 5% level.

Asparagus crowns, cv. 500-W, were transplanted into single-row plots 4 ft apart and 40 ft long (4 replications) in blocks of heater and non-heated soil on May 5, 1972. Crowns were placed 6 in. apart in furrows 8 in. deep and initially covered with about 4 in. of soil. By June 1, a good stand of asparagus was established and the crowns were covered with an additional 4 in. of soil.

Asparagus ferns were cut off at ground level on three random 10 ft row sections from heated and non-heated soil blocks and weighed on September 27, 1972. The fern and stalks were brown and dry at time of cutting.

Although asparagus spears are not usually cut the second season after crown transplanting, a single harvest was made on April 12, 1973. The new asparagus spears from the middle 10 ft of each plot were cut off at ground level, counted, and weighed.

Two year old asparagus crowns from 10 ft row sections in each plot were dug, counted, and weighed on April 30, 1973.

Results and Discussion--The first asparagus spears emerged May 10, 1972. Initial spear emergence and subsequent growth appeared to be more rapid on heated soil than on control blocks. By October 1972, crowns in heated soil appeared to have produced about 50 percent more fern growth than crowns in control soil (Figure 56). Asparagus fern on control plots was about 2 ft in height while fern on heated soil was at least 3 ft tall on October 4, 1972.

The weight of asparagus fern and stalks cut in September from soil heated plots averaged 95 percent more than from the control blocks (Table 12).

Early spring production of asparagus spears was stimulated by soil heat. On the harvest of April 12, 1973, the soil heated plots yielded 44 and

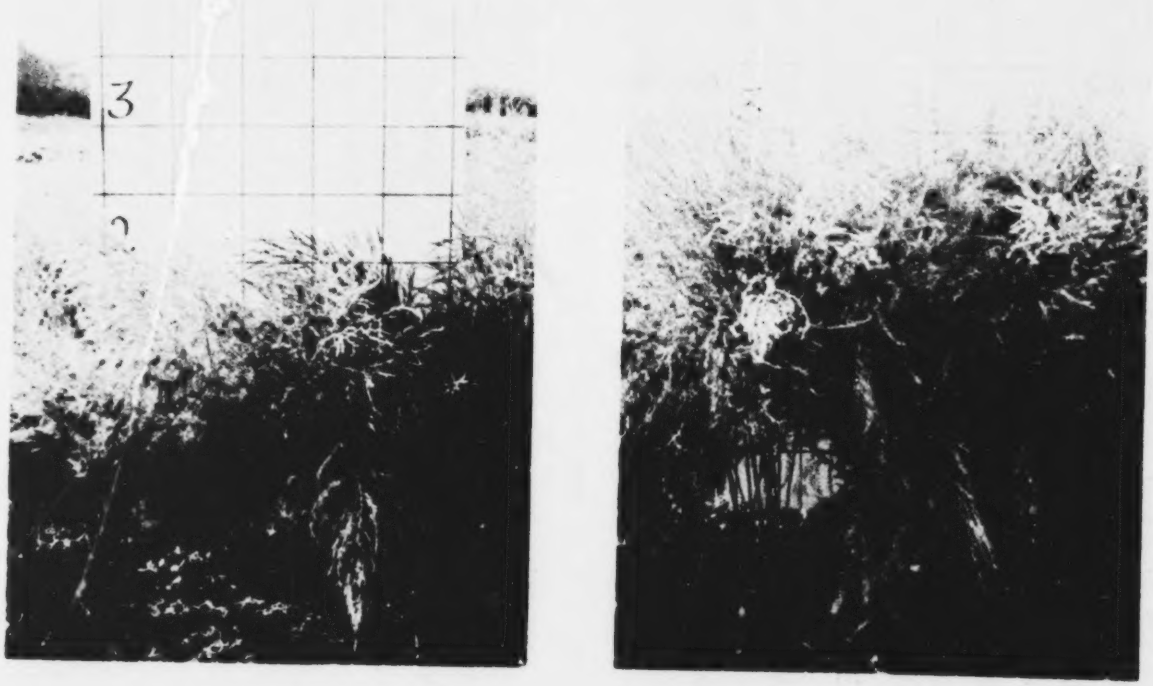

Figure 56: Comparison of first year asparagus fern growth of '500-W' on control soil (left) and on heated soil (right); pictures taken October 4, 1972.

Table 12. WEIGHT OF ASPARAGUS FERN AND STALKS PRODUCED ON SOIL HEATED AND NON-HEATED PLOTS; SAMPLES CUT SEPTEMBER 27, 1972[z]

Treatment	Average no. crowns per 10 ft of row sampled	Avg. wt (g) of fern and stalks per 10 ft of row
Soil heat	13.6	1,581
Control	13.6	810

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[z] Means within columns followed by different letter differ significantly at 5% level - Duncan's Multiple Range Test.

98 percent more asparagus spears than control plots based on number and weight, respectively (Table 13).

Two-year-old asparagus crowns were dug from heated and control plots in April 1973. The greater asparagus fern growth produced during the 1972 growing season on heated soil plots apparently resulted in larger crowns. Heated soil produced crowns that averaged about 40 percent larger than crowns from control areas (Table 14). The larger crowns should eventually produce greater yields of asparagus, but only prolonged experiments will determine the effect of heated soil on long-term asparagus yields.

Asparagus Nursery

Procedure--Fertilizer was broadcast at the rate of 300 lb 16-20-0 and 88 lb P per acre to the area for the asparagus nursery. 'Diazinon' was applied at the rate of 9.8 lb active material per acre. Fertilizer and insecticide were incorporated into the soil with a rototiller.

Asparagus seeds of cv. Mary Washington were planted about 2 in. apart with a Planet-Jr. seeder in rows 4 ft apart in soil heated and non-heated blocks on June 13, 1972. Each plot consisted of a single row and was replicated four times.

The crowns were dug, counted, and weighed from the middle 10 ft of row in each plot on April 5, 1973.

Results and Discussion--The production of 1 yr old asparagus crowns was not influenced by soil heat (Table 15).

The roots of the 1 yr old crowns were relatively shallow. The soil heat grid has least effect in the soil surface layers. Therefore, there may not have been much difference in soil temperature between heated and

Table 13. NUMBER AND WEIGHT OF FIRST HARVESTED ASPARAGUS SPEARS (APRIL 12, 1973) FROM 2 YEAR OLD CROWNS PLANTED IN HEATED AND NON-HEATED SOIL[z]

Treatment	Avg. no. spears per 10 ft plot	Avg. wt (g) per 10 ft plot
Soil heat	41.2a	3,420a
Control	28.5b	17,206b

[z] Means within columns followed by different letter differ significantly at 5% level - Duncan's Multiple Range Test.

Table 14. EFFECT OF SOIL HEAT ON WEIGHT OF 2 YEAR OLD ASPARAGUS CROWNS^z

APRIL 1973

Treatment	Avg. wt/crown -lbs
Soil heat	0.69a
Control	0.49b

[z] Means followed by different letters differ significantly at 5% level.

Table 15. WEIGHT AND NUMBER OF ONE YEAR OLD ASPARAGUS CROWNS PRODUCED ON HEATED AND NON-HEATED SOIL

	1 year old asparagus crown/plot	
Treatment	Average wt. g	Average number
Soil heat	692	52
Control	778	52

non-heated soil in the root zone of the asparagus crowns. Crown production might have been modified if different soil temperatures had been maintained.

Rhododendrons

Procedure--The following six cultivars of rhododendrons were planted in soil heated and non-heated control areas during the first two weeks of July 1971: 'Vulcan,' 'Jean Marie,' 'Fastausum Plena,' 'Lord Roberts,' 'Anna Krusckka,' and 'Old Port.'

Prior to transplanting, about 2 in. of sawdust and hemlock bark were incorporated 6 to 8 in. into the soil. The sawdust and bark were used to improve the water holding capacity of the soil and to form the lighter root ball required for plants dug for shipment.

Measurements of plant growth were made about one year after transplanting on July 19, 1972. Height was measured from soil surface to bud tips on four axes per plant. The maximum and minimum plant spreads were measured on the same plants that were used for height determinations. The cultivar blocks of rhododendrons on heated and control soil were not replicated, so height and spread measurements were made on 10 random plants per variety from heated and control soil blocks. The average values are in Tables 16 and 17.

Height and spread measurements were taken again on November 14 at the end of the 1972 growing season.

Results and Discussion--Plants of most cultivars from soil heated blocks were generally larger than from control blocks on July 19, 1972. However, some varieties did not respond as much to soil heat as others. 'Old Port' and 'Lord Roberts' responded least to heated soil (Table 16). Height of 'Old Port' was not influenced by soil heat, but maximum and

Table 16. GROWTH, PLANT HEIGHT AND SPREAD, OF RHODODENDRONS PRODUCED ON HEATED AND NON-HEATED SOIL: MEASUREMENTS MADE ON JULY 19, 1972

	Average plant height-inches[z]		% height increase of soil heated plants	Average plant spread-inches				% increase of soil heated plants over checks	
				Check		Soil heat			
	Check	Soil heat	over checks	Max.	Min.	Max.	Min.	In max. Spread	In min. Spread
Vulcan	10.1	11.8	17	11.4	8.7	13.6	11.3	19	30
Jean Marie	7.1	10.1	42	7.7	5.6	10.6	7.9	38	41
Fastousum Plena	10.9	13.4	23	10.5	6.5	12.6	9.7	20	49
Lord Roberts	10.7	11.2	5	11.8	8.4	12.0	8.9	2	6
Anna Krusckka	9.3	10.1	9	10.6	8.2	12.5	9.8	18	19
Old Port	11.5	11.5	0	11.4	9.5	12.8	10.0	12	5

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[z] Height measurements from 4 axes/plant (average of 10 plants) from which maximum and minimum measurements were taken.

Table 17. GROWTH, PLANT HEIGHT AND SPREAD, OF RHODODENDRONS PRODUCED ON HEATED AND NON-HEATED SOIL: MEASUREMENTS MADE ON NOVEMBER 14, 1972

	Average plant height-inches^z		% height increase of soil heated plants	Average plant spread-inches				% increase of soil heated plants over checks	
				Check		Soil heat			
	Check	Soil heat	over checks	Max.	Min.	Max.	Min.	In max. spread	In min. spread
Vulcan	14.8	14.5	0	16.2	11.3	17.3	13.7	7	21
Jean Marie	9.3	11.8	27	9.3	7.1	11.4	8.5	23	20
Fastousum Plena	12.8	14.9	38	13.9	8.8	14.7	11.9	6	35
Lord Roberts	12.5	12.8	2	14.1	10.4	13.5	10.3	0	0
Anna Krusckka	11.8	12.0	2	12.8	9.6	14.8	10.3	16	7
Old Port	13.4	14.4	7	15.0	11.0	17.0	12.9	13	17

^{z}Height measurements from 4 axes/plant (average of 10 plants) from which maximum and minimum measurements were taken.

minimum spread averaged 12 and 5 percent, respectively, greater than 'Old Port' control plants. 'Lord Roberts' plant from heated soil averaged only larger in spread and height than control plants.

On the other hand, maximum and minimum spread of 'Jean Marie' plants on soil heat were increased 38 and 41 percent, respectively, and height was increased by 42 percent compared to plant size on control soil blocks (Table 16). The growth response of 'Vulcan,' 'Fastausum Plena,' and 'Anna Krusckka' to soil heat was between that of 'Jean Marie' and 'Old Port.'

There was less difference in size between plants grown on heated and control soil by the end of the 1972 growing season than in July. On November 14, 1972, soil heated plants of 'Jean Marie' averaged 27 percent taller, 23 percent greater maximum, and 20 percent greater minimum spread than control plants (Table 17). By November, the small difference that had existed in size of 'Lord Roberts' plants in July was not apparent.

Although there was less difference in plant size between soil heated and control plants in November, most cultivars on soil heat still appeared more symmetrical and uniform in size. This is supported by the lower coefficients of variation for maximum-minimum spread of plants grown on heated soil compared to the controls (Table 18).

Generally, soil heated plants also had less variation in height than plants from control soil. 'Jean Marie,' 'Fastausum Plena,' 'Lord Roberts,' and 'Old Port' plants from control soil blocks had greater coefficients of variation for height than plants in soil heated blocks (Table 18).

Cantaloupes

Procedure--Plots were fertilized with 800 lb 16-20-0 per acre in a 1 ft wide band on top of the beds. "Diazinon" insecticide also was applied in

Table 18. COEFFICIENT OF VARIATION FOR PLANT HEIGHT AND SPREAD OF SIX RHODODENDRON VARIETIES GROWN IN NON-HEATED SOIL AND SOIL HEATED BY THERMAL WATER - NOVEMBER 14, 1972

	Coefficient of Variation - %			
	Height		Max.-min. spread	
	Check	Soil heat	Check	Soil heat
Vulcan	16.9	17.9	22.8	14.9
Jean Marie	31.3	19.6	29.5	18.9
Fastausum Plena	25.6	13.9	28.8	15.9
Lord Roberts	20.2	18.2	20.6	20.9
Anna Krusckka	17.8	19.4	20.0	20.2
Old Port	29.8	17.0	24.6	19.3

a wide band on top of the rows at the rate of 4 lb active per acre on May 26, 1972. The insecticide and fertilizer were incorporated into the soil with a rototiller.

Black plastic film (4-mil) was put down in rows over the incorporated fertilizer and insecticide on May 30, 1972. Rows were spaced 5 ft apart. About 2 ft of plastic were exposed on top of each bed with 6 in. buried on each side of the bed. Five inch diameter holes were punched into the plastic every 4 ft. The plastic mulch was placed over heated and non-heated soil. Two cantaloupe cultivars, 'Supermarket' and 'Harper's Hybrid,' were seeded on June 2, 1972, in heated and non-heated soil and replicated twice. Seeds were planted 1 in. deep in each hole punched in the plastic mulch (4 ft x 5 ft plant spacing). Muskmelons were harvested from 40 ft plots starting on September 5 and ending on October 19, 1972. Fruit were separated into grades of U.S. No. 1, Commercial, Unmarketable, and Immature.[41]

Results and Discussion--Soil heat speeded early vine development of muskmelons (Figure 57). The area in the foreground of Figure 57 is non-heated soil and the area between rows is not covered with melon vines. The melons in the background of Figure 57 are on heated soil, and the areas between rows were completely covered with vines by mid-July.

Although early vegetative growth of cantaloupes was stimulated by soil heat, the yield of fruit was not. There was no significant difference in yield of soil heated and control areas of 'Harper's Hybrid' and 'Supermarket' in this study (Tables 19 and 20). Soil heat appeared to delay fruit maturity as indicated by the number of immature fruit at the end of the harvest season (Tables 19 and 20), but this has to be confirmed in other studies. Temperatures of heated soil at 6 and 12 in. depths were generally warmer through June and into July than non-heated soil (Figures 50 and 51), and this probably accounts for the early stimulation of vegetative growth of cantaloupe plants. Perhaps a different

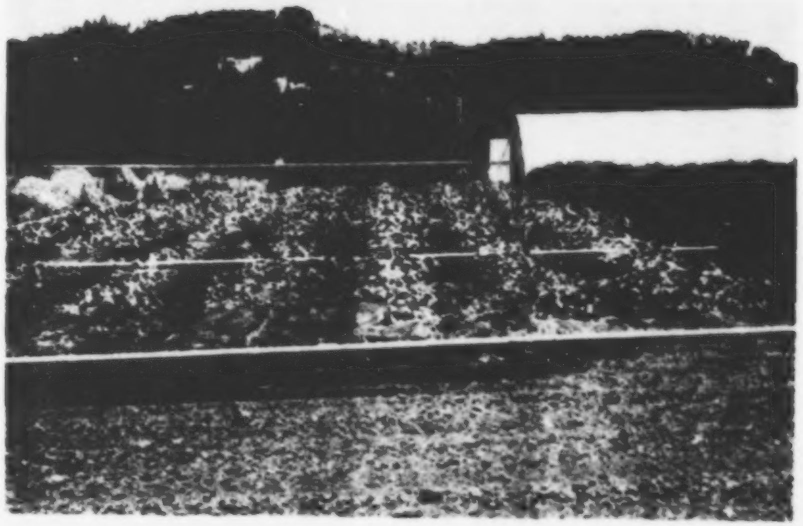

Figure 57: Muskmelon vine development on non-heated soil (foreground 1/2 of melon block) and heated soil (background 1/2 of block).

Table 19. EFFECT OF SOIL HEAT ON GRADE AND YIELD OF CANTALOUPE 'HARPER'S HYBRID'

	Lbs/Acre			
	U.S. no.1	U.S. commercial	Unmarketable (rots & splits)	Immature
Soil heat	4215	523	2780	918
Control	8059	1329	1147	373

Table 20. EFFECT OF SOIL HEAT ON GRADE AND YIELD OF CANTALOUPE 'SUPERMARKET'

	Lbs/Acre			
	U.S. no.1	U.S. commercial	Unmarketable (rots & splits)	Immature
Soil heat	3989	1220	1729	2301
Control	7498	2110	485	518

growing season, planting date, or soil temperature range would have altered the effect of soil heat on yields.

Squash

Procedure--'Table Queen' squash was seeded through black plastic mulch on heated and non-heated soil on June 24, 1972. Hill spacing was 4 ft x 6 ft. The planting was not replicated. Fertilizer and insecticide quantity, type, and date of applications are the same as outlined for cantaloupes. 'Table Queen' squash was first harvested on October 4, 1972. Only good, mature fruit without cracks and free of disease were counted on each harvest.

Results and Discussion--The soil heated block of squash produced 24 percent more fruit by number and 13 percent more fruit by weight than the non-heated control block (Table 21). In this case, early maturity of squash appeared to be enhanced by the soil heat. At first harvest, the yield from the soil heated block was 10.2 tons; control yielded only 3.5 tons (Figure 58). The 10.2 tons of fruit represented 36.2 percent of the heated block's production, while the control had only produced 14.1 percent by October 4, 1972. Production from control and heated block was about the same on October 9 and 16. On the last harvest, November 6, the control block produced 4.6 more tons per acre than the soil heated block.

Table 21. YIELD OF 'TABLE QUEEN' SQUASH PRODUCED ON A CONTROL AND SOIL HEATED BLOCK

Harvest date	Number of fruit/A.[z]		Tons fruit/A.[z]	
	Soil heat	Control	Soil heat	Control
10/4/72	10,010	3,276	10.2	3.5
10/9/72	4,368	2,912	3.9	3.3
10/16/72	2,548	1,820	2.0	1.5
11/6/72	14,560	17,472	12.0	16.6
	31,486	25,480	28.1	24.9

[z] Plant spacing was 4 X 6 ft.

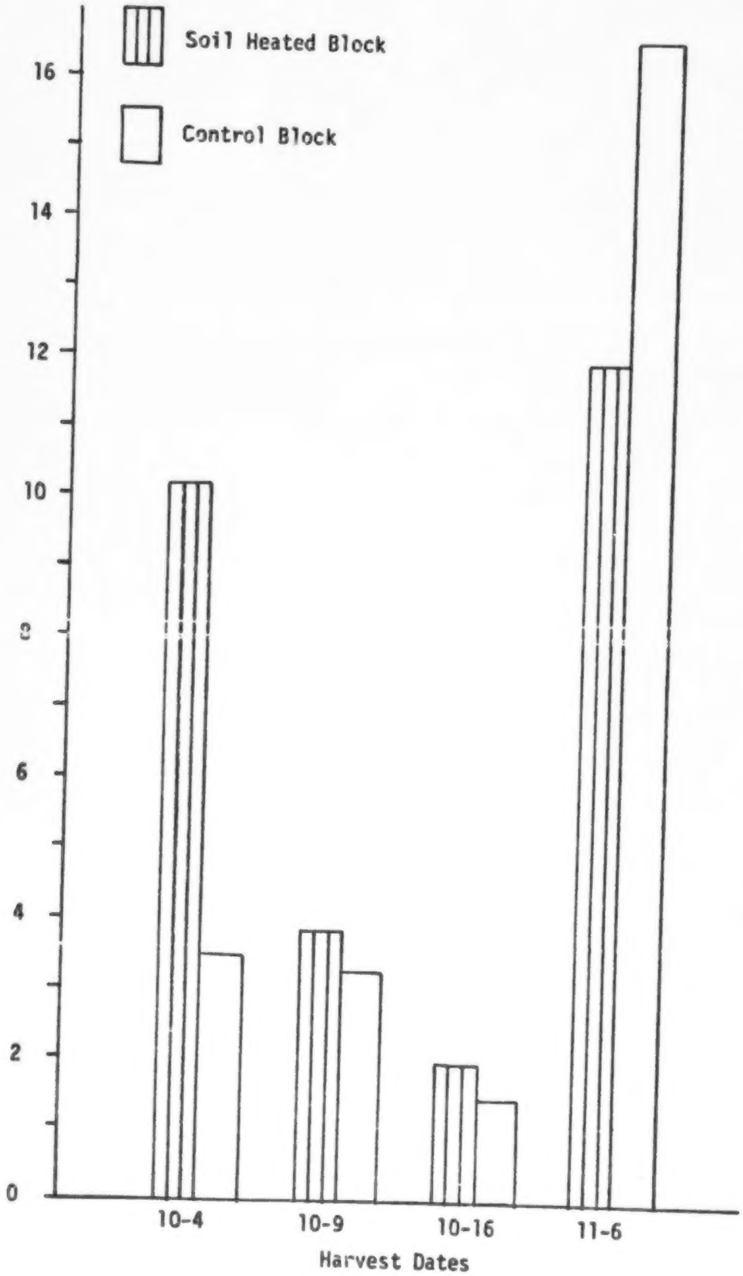

Figure 58. Yield of Table Queen squash on four harvest dates during 1972.

SECTION VI

SOIL HEATED GREENHOUSE

Initially, the idea was to keep greenhouse construction simple, relatively inexpensive, and to use the structure to lengthen the time in spring and fall that the undersoil heated block could be used for cropping. However, because of the relatively mild climate in the Eugene area, it was found that year-around cropping was possible with selected crops in the simple greenhouse structure described below. The crops grown and their production in the greenhouse will be covered in subsequent sections.

A 55 by 22 ft "Port-a-Green" plastic film greenhouse was constructed over a portion of the large under-soil heated block in January 1972. The soil underneath and surrounding the greenhouse was heated by thermal water circulated through 2-1/2 in. diameter plastic pipe, buried about 26 in., and spaced 60 in. apart (for complete description, see Section V). Ventilation fans were installed in the greenhouse, but no supplemental heaters were added. The only heat in the greenhouse was that radiated from the buried soil heat grid and the solar energy trapped in the greenhouse during the day.

GREENHOUSE AIR TEMPERATURES

Maximum greenhouse temperatures were dependent to a large degree upon daily solar energy, but greenhouse highs were modified by the thermostat controlled ventilation fans. Even when the air temperature was cold, greenhouse highs during the day were relatively warm if there was no cloud cover. For example, December 8, 1972, was a clear day with a maximum air temperature of only 15°F but maximum greenhouse temperature reached 55°F (Figure 59). December 20, 1972, was cloudy (not as cold) and

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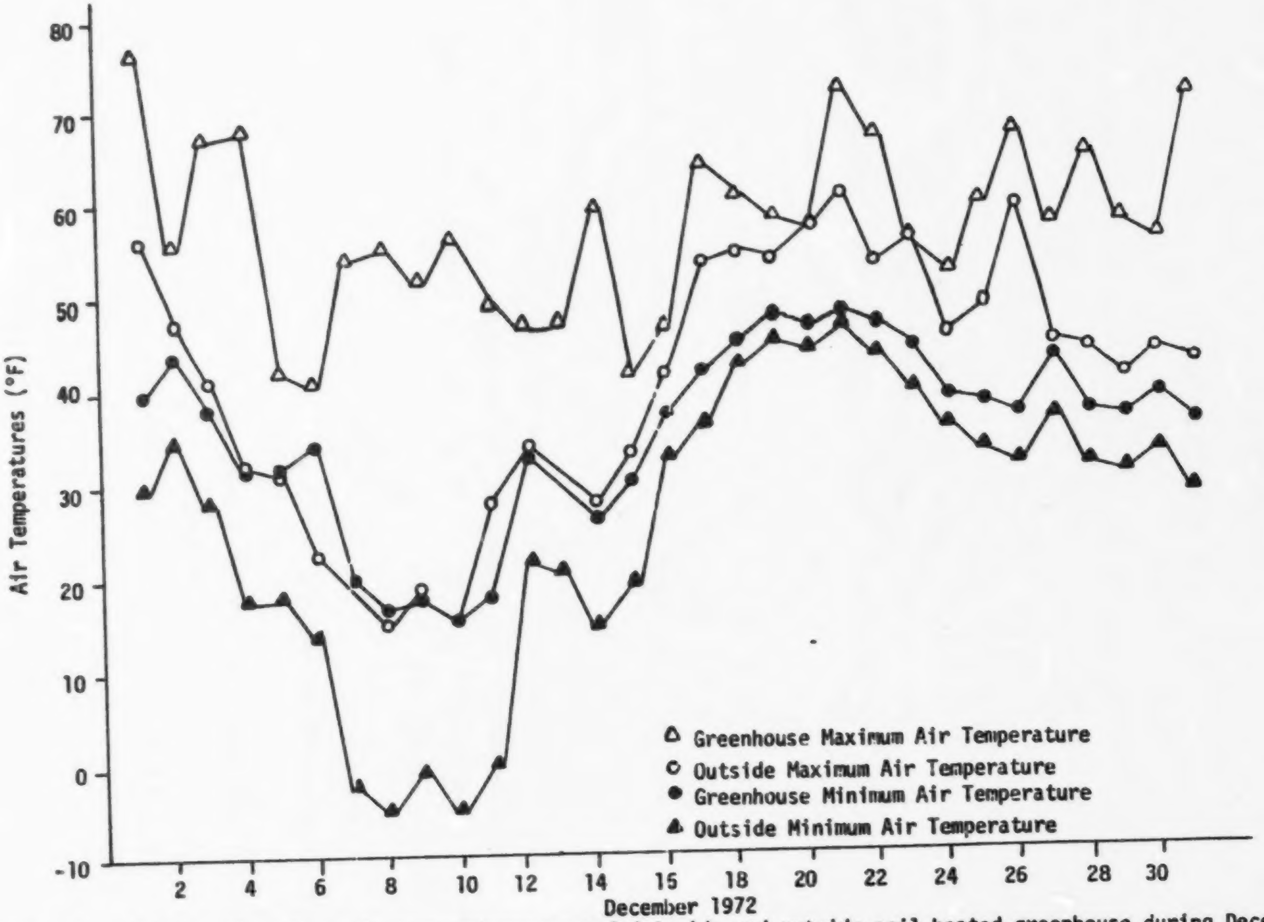

Figure 59. Minimum and maximum air temperatures recorded inside and outside soil heated greenhouse during December 1972.

maximum temperatures inside and outside the greenhouse were the same. Another reason that greenhouse maximum temperatures were no higher than outside the house was that thermal water flow was interrupted on this and several other dates during December 1972. The temperature of thermal water during December was also cooler than usual.

Only the minimum temperatures inside and outside of the greenhouse, 5 ft above the ground, are included in Figure 60. Greenhouse minimums averaged 8.2°F higher than ambient minimums for the March 1972 through March 1973 period. There was often less difference between minimum temperature inside and outside the greenhouse during the summer than during the winter. This was because greenhouse doors were often left open during the summer for added ventilation. The least difference between greenhouse and outside minimums occurred during the week of August 9, 1972 (.2°F difference), and the largest difference occurred during the week of December 6, 1972 (19°F difference). Greenhouse minimums may have been somewhat warmer during December 1972 if thermal water temperatures had been warmer.

GREENHOUSE SOIL TEMPERATURES

As already stated, greenhouse soils were heated by the buried thermal water grid described in Section V. The soil heat grid by itself modified soil temperatures, and the addition of a greenhouse further modified temperatures of soil beneath the structure.

Platinum bulb temperature sensors connected to chart-type recorders were placed at 6, 12, and 24 in. depths in a vertical line above and halfway between buried heat pipes (Figure 48) within the greenhouse.

Greenhouse soil temperatures at 6, 12, and 24 in. depths were modified by the thermal water circulated through the buried soil heat grid. As was the case with the soil heated block outside the greenhouse, temperatures were not uniform for any given depth in a horizontal line across the soil

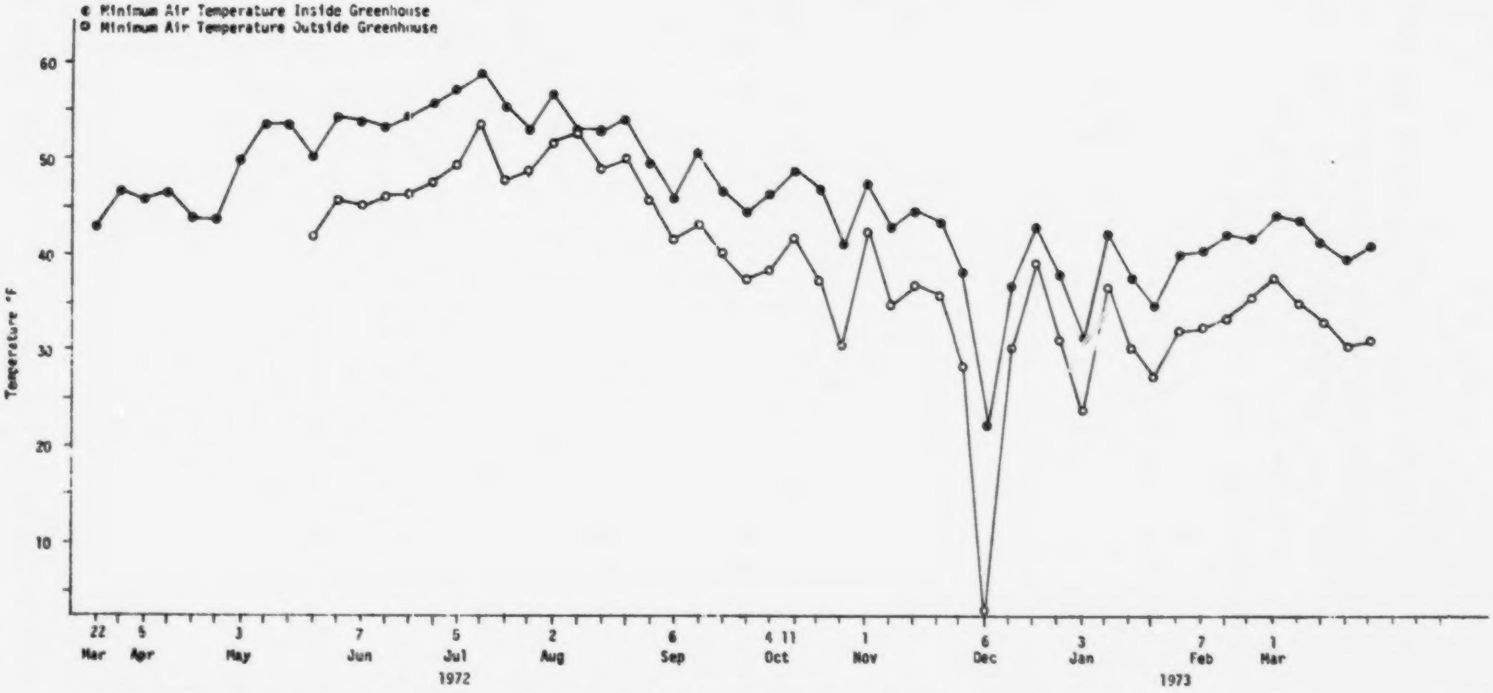

Figure 60. Comparison of mean weekly minimum temperatures inside and outside the greenhouse at about 5 ft above the ground.

profile. Soil farthest away from the buried heat pipes was cooler than soil closer to the heat lines. However, the temperature difference between soil temperature midway between and nearest to the pipes was generally less in the heated greenhouse soil than in the heated soil outside the greenhouse. For example, the average temperature difference in soil at points midway between (coolest heated soil) and nearest (warmest heated soil) heat lines at 12 and 24 in. depths averaged 1.9°F (Figure 61) and 6.2°F (Figure 62) in the greenhouse and 4.3°F (Figure 51) and 17.4°F (Figure 52) in heated soil outside the greenhouse, respectively. The reduction of radiated heat loss from the soil by the greenhouse structure apparently helped maintain more uniform temperatures in a horizontal line across the soil profile.

The warmest areas of heated greenhouse soil at the 6 in. depth (recorded in a vertical line above heat pipes) averaged 9.5°F warmer than unheated control soil for the recorded periods from May 1972 through January 1973 (Figure 63). During the May through July period, greenhouse soil temperatures were recorded beneath rows of trellised tomatoes. Soil temperatures outside the greenhouse were recorded beneath low growing field tomatoes. Greenhouse tomatoes were between 5 and 6 ft tall and formed a continuous plant cover inside the greenhouse. With vegetation of such thickness, the ground surface loses its function as a boundary surface with the atmosphere and site of major heat exchange. The radiation received by the greenhouse soil was not as great as if the ground were bare and probably not as great as received by soil outside the greenhouse with the low growing, less dense field tomatoes. The difference in foliage cover probably accounts for the lower 6 in. depth soil temperatures recorded in the greenhouse during the May through July period.

Temperatures of heated greenhouse soil at the 12 in. depth were modified relatively more than 6 in. depth temperatures. The warmest areas of greenhouse soil at the 12 in. depth averaged 11.2°F higher than controls for the recorded periods between May 1972 and January 1973 (Figure 61); the coolest areas of greenhouse soil averaged 9.3°F warmer than control

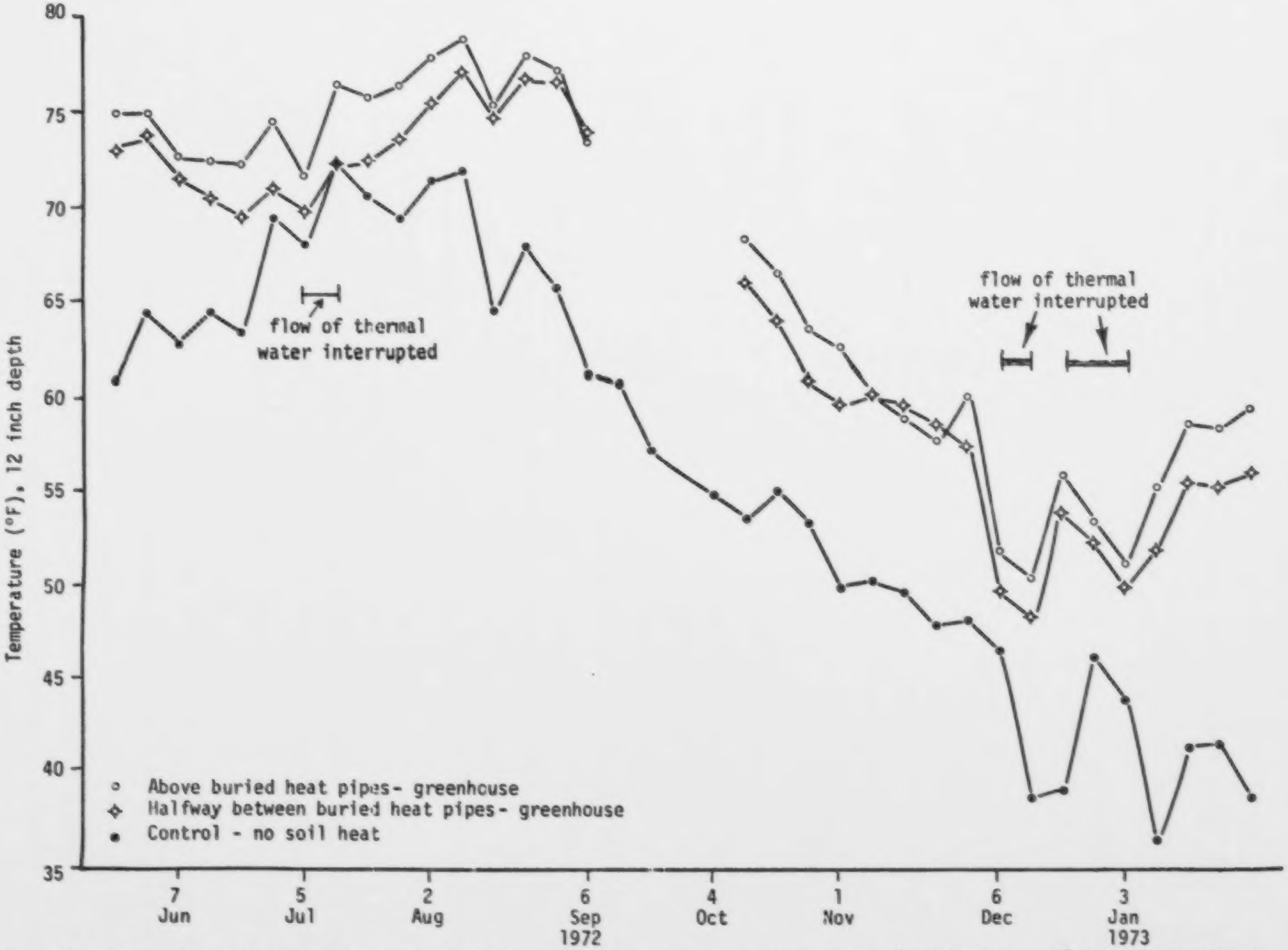

Figure 61. Comparison of mean weekly 12 inch depth soil temperatures recorded at two locations in soil heated greenhouse with non-heated soil outside greenhouse: greenhouse soil was heated with thermal water circulated through plastic pipes buried 26 inches and spaced 5 ft apart.

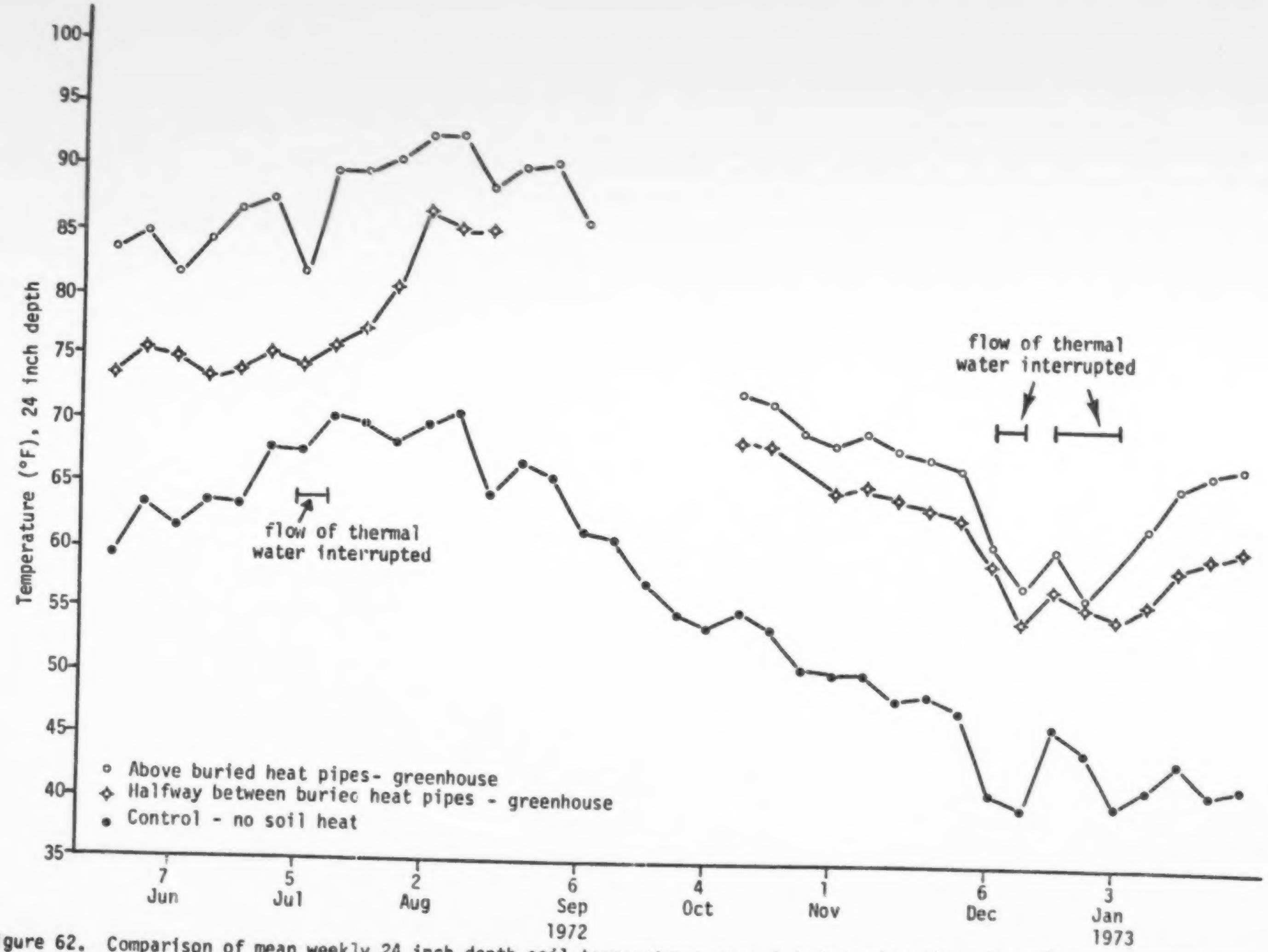

Figure 62. Comparison of mean weekly 24 inch depth soil temperatures recorded at two locations in soil heated greenhouse with non-heated soil outside greenhouse: greenhouse soil was heated with thermal water circulated through plastic pipes buried 26 inches and spaced 5 ft apart.

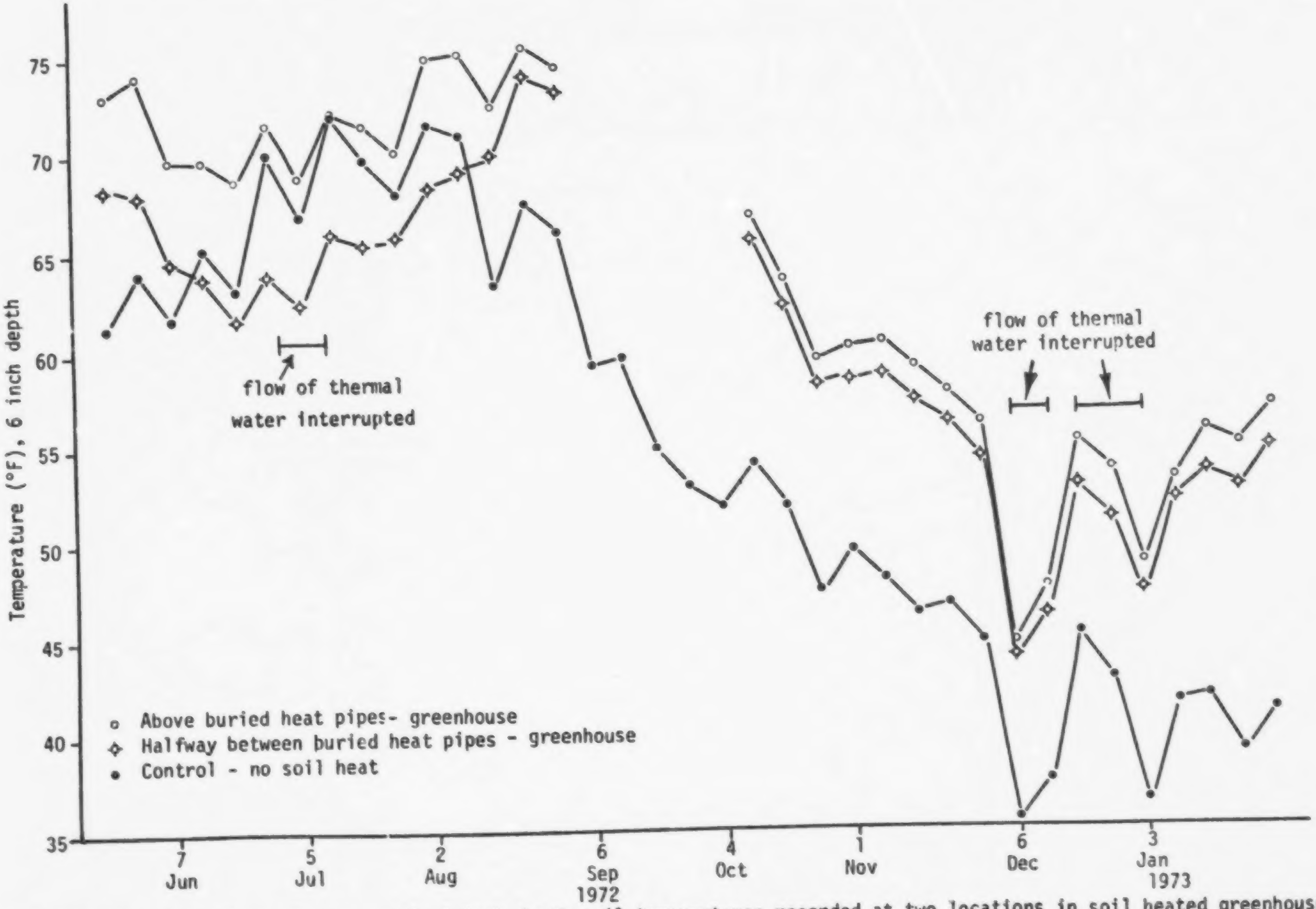

Figure 63. Comparison of mean weekly 6 inch depth soil temperatures recorded at two locations in soil heated greenhouse with non-heated soil outside greenhouse: greenhouse soil was heated with thermal water circulated through plastic pipes buried 26 inches and spaced 5 ft. apart.

soil during the same period. The 12 in. depth greenhouse soils averaged 3.1 to 5.7°F warmer than the 12 in. depth in the heated soil block outside the greenhouse.

The greatest temperature difference between greenhouse and control soil occurred at the 24 in. depth. The warmest areas of greenhouse soils averaged 20.7°F warmer than control soil, and the coolest greenhouse areas of greenhouse soil averaged 14.2°F warmer than control soil at the 24 in. depth (Figure 62).

GREENHOUSE CROP PRODUCTION

A variety of crops were grown in the greenhouse, some of which are not normally considered to be greenhouse crops. This was done to determine if crops that are tolerant to cool temperatures could be produced through the winter in the greenhouse when low light intensity and coolest temperatures prevail.

Interest was expressed in the value of these crops. In order to put an economic value on the crops, Portland market wholesale prices[42] were assigned to the crops during the time they were harvested. Therefore, some of the crops may have been worth more or less if harvested at other times of the year than was done in these studies. The dollar value for the crops is higher than received at the farm. No real attempt was made to study market supplies and gear specific crop production to periods of least supply and highest price. However, this would be an important consideration if studies continued or a large scale project were undertaken. The main emphasis in the following studies was to obtain approximate yield estimates for various crops grown in the simple greenhouse constructed over a portion of the heated soil block.

Leaf Lettuce

Transplants of 'Bibb' and 'Grand Rapids' leaf lettuce were obtained from a local greenhouse nursery and transplanted into the project's greenhouse on March 8 and 9, 1972. Plant spacing was 6 by 6 and 8 by 8 in. for 'Bibb' and 'Grand Rapids,' respectively. The two leaf lettuce cultivars were transplanted into 9 by 10 ft blocks of 4 mil black plastic and aluminum foil mulches and in non-mulched control blocks.

The lettuce crop was harvested (Figure 64) on April 24, 1972; yield and estimated crop values are given in Table 22. Dollar values in Table 22 are based on Portland wholesale market prices reported by USDA Agricultural Marketing Service for April 24, 1972.[43]

If all 'Bibb' and 'Grand Rapids' plants had been spaced on exactly 6 by 6 and 8 by 8 in. spacing, respectively, there would have been the equivalent of about 174,240 'Bibb' and 'Grand Rapids' plants per acre. The primary reason that plant populations reported in Table 22 are lower than the possible maximum is that transplants were placed slightly further apart than the intended 6 by 6 and 8 by 8 in. spacings.

A few plants had to be discarded shortly before or at harvest because of disease (appeared to be Sclerotinia soft rot). Although there was very little disease, more soft rot occurred in the check areas (about 3 percent of plants) than in the black plastic and aluminum foil mulched plots (less than 1 percent diseased plants). Although the greenhouse soil was not sterilized before planting, disease contributed little to reducing harvested plant number.

The black plastic and aluminum foil mulch materials were included to determine if they would influence soil temperatures. Initially, when lettuce plants were small, surface soil temperatures were slightly warmer underneath the mulches than in check plots. As soon as the plant canopy developed over the entire soil surface, temperatures underneath the mulches were no different than in the check plots. The mulch materials did reduce plant foliage contact with the bare soil and thus reduced the incidence of disease.

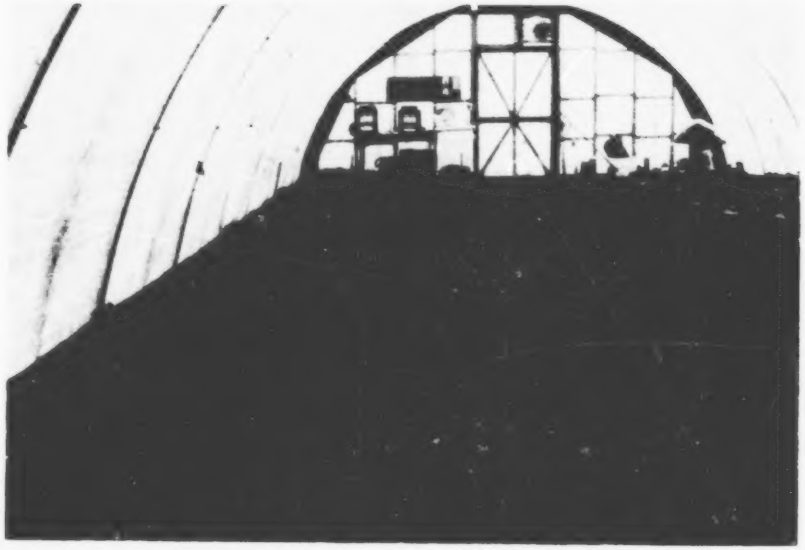

Figure 64: Greenhouse lettuce on April 24, 1972.

Table 22. YIELD AND ESTIMATED VALUE OF BIBB AND GRAND RAPIDS LEAF LETTUCE GROWN IN THE PROJECT'S GREENHOUSE ON CHECK, BLACK PLASTIC FILM, AND ALUMINUM FOIL MULCHES; HARVESTED ON APRIL 24, 1972.

	CHECK		BLACK PLASTIC		ALUMINUM FOIL	
	Grand Rapids	Bibb	Grand Rapids	Bibb	Grand Rapids	Bibb
No. of plants harvested/acre	81,556	127,188	81,556	151,460	87,381	161,169
Pounds of lettuce/acre	65,701	60,089	63,672	56,019	66,099	64,264
No. of 2 doz crates/acre	3,398	5,299	3,398	6,311	3,641	6,715
Value/Acre: at						
$1.60/2 doz crate[a]	$5,437	$8,478	$5,437	$10,098	$5,826	$10,744
$2.25/2 doz crate[a]	$7,645	$11,923	$7,645	$14,200	$8,192	$15,109

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[a] Value based on wholesale price range received in Portland, on April 24, 1972, for California butter and leaf lettuce.

Forty to 50,000 lbs 'Grand Rapids' and 20,000 to 25,000 lbs 'Bibb' lettuce per acre are considered to be good yields for greenhouse leaf lettuce.[44] The yield of 'Grand Rapids' in the project greenhouse ranged from about 63,672 to 66,099 lbs per acre and the yield of 'Bibb' lettuce ranged from 56,019 to 64,264 lbs per acre (Table 22). The yields of both leaf-type lettuce compare very favorably with yields of leaf lettuce produced in conventionally heated greenhouses. Because of the short time needed to produce a greenhouse lettuce crop, multiple crops of lettuce could be produced each year depending upon the marketing situation.

The wholesale value of the crop on April 24, 1972, ranged from about $5,400 to $8,200 per acre for 'Grand Rapids' and $8,400 to $15,000 per acre for 'Bibb' (Table 22). The value of the crop could range higher than reported here depending upon market supply and demand. For example, the wholesale price for Oregon grown butter and leaf lettuce at the Portland market was $3 per 2-dz crate on May 8, 1972, or about 33 percent more than the top value used in Table 22.

A second planting of greenhouse lettuce was made in the fall of 1972. 'Bibb' and 'Grand Rapids' lettuce were seeded in flats of vermiculite and placed in the project's greenhouse on October 5, 1972, to germinate. Small 'Bibb' and 'Grand Rapids' lettuce plants were transplanted on 6 by 6 and 8 by 8 in. spacings, respectively, on November 1, 1972. Each cultivar was placed in a 5 x 14 ft ground bed.

Ambient air temperatures for December 4 through 12, 1972, averaged 10 to 26°F below normal,[45] and the subzero lows in most of Oregon set many new December and all-time records. A record low of -12°F was recorded at the Eugene airport on December 8, 1972. At the project site, lows of -5°F were recorded on December 8 and 10, 1972.

The delivery of thermal water to the project was interrupted several times during December. The Weyerhaeuser plant had to stop pumping thermal water on December 8 and 11 in order to make repairs. A joint in the 16 in. steel mainline developed a leak on December 12, but was repaired by the evening of December 13. No thermal water was pumped to the project from December 22, 1972, to January 2, 1973. The Weyerhaeuser plant was down December 22 through 26 for the Christmas holidays. Thermal water was delivered to the pumping pit from December 27, 1972, through January 1, 1973, but the volume was not great enough to be pumped to the project. This is why in Figure 3 thermal water temperature at the pumping pit was going up while soil heat grid inlet and outlet temperatures were going down.

The low ambient air temperature outside the greenhouse on December 7 was near 0°F, and the low greenhouse temperature was 20°F at 5 ft above ground. The following night, December 8, a low of -5°F was recorded outside the greenhouse and a low of 17°F inside the house at the 5 ft height. 'Bibb' and 'Grand Rapids' leaf lettuce were not frozen by low temperatures during the coldest weather. Greenhouse air temperatures remained at 36°F at the 1 ft level and slightly warmer within the plant foliage on the coldest nights. Apparently enough heat was radiated from the soil to keep temperatures above freezing to a height of more than 1 ft in the greenhouse. Temperatures outside the greenhouse were probably coldest near the ground but greenhouse temperatures were warmest near the soil because of heat radiated from the buried thermal water grid. Greenhouse soil and air temperatures may have been somewhat warmer during this cold December period if the thermal water supply had been warmer and had not been interrupted.

The growth of the lettuce plants was slow because of relatively low temperatures and the low light quality experienced during the winter months. Disease was more of a problem in the second crop than in the first, and 'Grand Rapids' was more susceptible than 'Bibb.' By the end of December, nearly 25 percent of the 'Grand Rapids' plants were removed because of soft-rot-type decay, but only about 9 percent of the 'Bibb' plants had to be removed for this reason.

Tomatoes

Most greenhouse tomatoes are grown on a trellis system where the main plant axis is trained to a string suspended from overhead wires. All lateral plant branches are removed by hand from the main plant axis. The labor requirement for this method is high but increased yields, less disease, greater air circulation through the foliage, and ease of harvest make the system economical.

At the time the first tomato crop was planted in the project's greenhouse, no overhead trellis was available. Therefore, the tomatoes were either trained to 5 ft stakes or allowed to grow on the ground. The stake system kept fruits off the ground, helped air movement (in addition to the removal of excess foliage), reduced disease, and made it possible to use more plants per acre than when plants were grown on the ground.

The first planting of tomatoes in the greenhouse was made in February 1972. Cultivars 'H. 1439,' 'Fireball,' and 'H. 1350' were seeded at a high rate in short rows in the greenhouse soil on February 17, 1972. Soil temperature at the 6 in. depth was about 64°F at time of seeding.

'H. 1439' plants were transplanted from the closely spaced seedling rows to double rows 1 ft apart with plants 1 ft apart in the row. Double rows were on 4 ft centers. The 'H. 1439' yield record block contained 28 plants.

'H. 1350' and 'Fireball' were transplanted from the short closely spaced seedling rows into rows with about 1-1/2 in. between plants on March 16, 1972. They were transplanted again on May 2, 1972, to a 4 by 2 ft spacing. The blocks of 'Fireball' and 'H. 1350' contained 24 plants each.

On May 9, 1972, transplants of tomato cultivar 'Willamette' were obtained from the McKenzie Nursery and transplanted to the greenhouse in a block of 24 plants on 2 by 4 ft spacings. 'Willamette' plants were smaller and less mature than the other cultivars. These transplants were also placed outside the greenhouse in heated and non-heated soil on the same day.

Plant spacing of 'H. 1350,' 'Fireball,' and 'Willamette' was equivalent to 5,445 plants per acre (8 ft^2/plant); the spacing of 'H. 1439' was equivalent to 14,520 plants per acre (3 ft^2/plant). 'H. 1439' vines were trained on stakes with two main branches per plant. 'Fireball,' 'H. 1350,' and 'Willamette' were grown on the ground like normally grown field tomatoes.

Pollination of greenhouse tomatoes was induced by the air blast from a small engine-driven backpack sprayer-duster.

Prior to the time that tomato cultivars were transplanted, 625 lbs of 16-20-20 fertilizer were incorporated into the greenhouse soil with a rototiller on April 28, 1972. Periodic applications of 9-45-15 and/or potassium nitrate fertilizer were applied to the plants as a liquid and watered into the soil surrounding the tomato plants during the growing season.

The first greenhouse tomato crop was planted relatively late, and fruit matured when field-grown tomatoes from California were plentiful and when some local tomatoes were available. Although greenhouse tomatoes usually receive a premium price above field tomatoes, the Portland market wholesale price for field tomatoes was assigned to the greenhouse crop. Table 23 lists the wholesale price for field-grown tomatoes of various sizes from July 13 through September 21, 1972. Greenhouse fruit were not graded for size, but it was estimated that all marketable fruit were at least grade size 6 x 7 (2-1/16 in. minimum to 2-10/16 maximum diameter) or larger. The net weight of a 3-layered 6 x 7 tomato lug is 30 lbs with about 126 fruit per lug[46] and an average fruit weight of about .23 lb.

Tomato cultivars grown in the greenhouse produced 32 to 76 tons of marketable fruit per acre (Table 24) during the harvest period of

Table 23. WHOLESALE MARKET PRICE PER LUG BOX OF CALIFORNIA PINKS AND RIPE TOMATOES ON PORTLAND MARKET DURING PERIOD OF JULY 13 THROUGH SEPTEMBER 21, 1972.[a] (FIELD GROWN TOMATOES)

1972 Date	2-Layer Lug 5 X 6's		3-Layer Lug 6 X 6's		3-Layer Lug 6 X 7's		3-Layer Lug 7 X 7's	
Jul 13	$5.00 -	$5.75	$7.50 -	$8.20	$6.50 -	$7.25	$6.00 -	$6.75
17	4.50	5.00	5.25	6.00	5.00	5.50	4.50	5.00
20	4.50	5.00	5.25	6.00	5.00	5.50	4.50	5.00
24	5.25	5.50	5.25	6.00	5.75	6.00	4.75	5.50
27	5.00	5.50	7.00	7.25	6.00	6.75	4.75	5.50
31	5.25	5.75	7.00	7.25	6.26	6.75	5.50	6.00
Aug 3	5.75	6.25	7.25	8.20	6.75	7.25	5.50	6.00
7	5.00	6.25	-	-	5.50	6.50	5.00	5.50
10	5.00	5.50	-	-	6.25	6.50	5.00	5.50
14	5.00	5.50	6.50	7.50	6.25	7.70	4.25	5.00
17	5.50	6.50	6.75	7.50	5.50	7.70	4.25	5.75
21	5.75	6.00	7.25	8.20	6.00	6.75	5.50	5.75
24	5.75	6.00	7.25	8.20	5.50	6.50	5.00	5.50
28	5.75	6.00	7.25	8.20	6.50	7.70	5.50	6.70
31	5.50	5.90	7.70	8.20	6.00	7.20	5.00	6.20
Sep 5	4.50	4.70	5.50	6.70	4.75	5.25	4.50	5.20
7	3.90	4.75	5.50	6.70	4.75	5.25	4.50	5.20
11	4.70	5.00	6.00	6.70	5.50	5.75	5.00	5.25
14	5.00	5.50	6.00	7.70	5.50	5.75	5.25	6.20
18	5.25	5.70	7.00	7.70	6.00	7.20	5.25	6.20
21	5.25	6.00	7.00	8.20	6.25	7.25	5.75	6.75
Mean 7/13-9/21	5.10	5.62	6.54	7.39	5.79	6.57	5.01	5.74

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[a] Prices from Fresh Fruit and Vegetable Market News - Portland Daily Report - Vol. LXI. No's 4 through 16. USDA, Ag. Market Service.

Table 24. WEIGHT, NUMBER OF 6 X 7 LUGS (126 FRUIT/LUG), AND ESTIMATED WHOLESALE VALUE OF TOMATOES PRODUCED IN SOIL HEATED GREENHOUSE.

Tomato Variety	1972 Harvest Period	Tons Marketable Fruit/Acre	Aug Fruit Wt-Lbs	Number of Marketable 3-layered 6X7 Lugs/Acre	Wholesale Value/Acre $5.79/Lug Mean Low	Wholesale Value/Acre $6.57/Lug Mean High	No. 816 Boxes/Acre x 100	Market-able Fruit/ plant lbs
H.1439[a]	Jul 14-Sep 12	76.1	.25	4,783	$27,693	$37,424	190	10.5
H.1350[b]	Jul 22-Sep 12	34.0	.23	2,299	$13,311	$15,104	85	12.5
Fireball[b]	Jul 14-Sep 12	32.0	.23	2,174	$12,587	$14,283	79	11.7
Willamette[b]	Jul 29-Sep 12	33.9	.26	2,036	$11,788	$13,376	85	12.5

[a] Plants staked (14,500 plants/acre).

[b] Plants grown on ground like most field-grown tomatoes (5,445 plants/acre).

mid-July through mid-September. Tomato plants were removed from the greenhouse on September 12, 1972, so that the soil could be prepared for another planting of vegetables. There was the equivalent of 20, 10, and 4.8 tons green fruit per acre left of 'H. 1439,' 'Willamette,' and 'H. 1350,' respectively, when plants were removed. Many of these fruit would have been marketable if they had been allowed to mature. Cultivar 'H. 1439' produced more than twice the yield of other cultivars listed in Table 24. The yield difference was primarily because of training systems used with the different cultivars. Many fruits of cultivars grown on the ground developed ground rot and had to be discarded; therefore, their yields were reduced.

The value of the greenhouse crop was calculated in two ways. The first was based on the Portland wholesale price received for field-grown tomatoes during the period that the greenhouse crop was harvested. The second was based on approximate prices received for greenhouse tomatoes on the Chicago market.

Individual 'Fireball' and 'H. 1350' fruit averaged about .23 lb and 'H. 1439' and 'Willamette' were somewhat larger (Table 24). Therefore, fruit of the latter two cultivars averaged somewhat larger than 6 x 7's and would have been worth more than that indicated in Table 24. The wholesale values per acre based on average low and high Portland market tomato prices during the harvest period (Table 23) for production of 3-layered 6 x 7 lugs are included in Table 24. The value per acre ranged from $11,788 for 'Willamette' to $37,424 for 'H. 1439.'

Greenhouse tomatoes sold on the Chicago market are usually sold in 8 lb cardboard baskets. Table 25 lists a production range of 8 lb baskets and prices received for greenhouse tomatoes in the Chicago area in 1965.[47] Costs may have to be adjusted to bring them in line with present costs; however, the prices are probably still within the range being paid for greenhouse tomatoes. The number of 8 lb boxes produced by each variety (Table 24) was assigned to the appropriate production level in Table 25, and the values per acre estimates are as follows:

Table[d] 25. GROSS CASH RETURNS, LESS DIRECT MARKETING COSTS, AT FOUR PRICE LEVELS FOR DIFFERENT VOLUMES OF PRODUCTION

Production of 8-lb baskets	Cost of basket and hauling[a]	Average prices of 8-lb basket			
		$1.50 (1.35)[b]	$1.75 (1.57)	$2.00 (1.80)	$2.25 (2.02)
		Total gross cash returns less direct marketing costs[c]			
2,000	$ 600	$ 2,100	$ 2,540	$ 3,000	$ 3,440
4,000	1,200	4,200	5,080	6,000	6,880
6,000	1,800	6,300	7,620	9,000	10,320
8,000	2,400	8,400	10,160	12,000	13,760
10,000	3,000	10,500	12,700	15,000	17,200
12,000	3,600	12,600	15,240	18,000	20,640
14,000	4,200	14,700	17,780	21,000	24,080
16,000	4,800	16,800	20,320	24,000	27,520
18,000	5,400	18,900	22,860	27,000	30,960
20,000	6,000	21,000	25,400	30,000	34,400
22,000	6,600	23,100	27,940	33,000	37,840
24,000	7,200	25,200	30,480	36,000	41,280
26,000	7,800	27,300	33,020	39,000	44,720

[a] Calculated at 30 cents per 8-lb basket (14 cents for basket, lid and paper and 16 cents for hauling).

[b] Figures in parentheses are grower's returns per basket minus 10 per cent commission.

[c] Direct marketing costs are cost of basket, hauling, and commission.

[d] Table from Courter, J. W. et al. 1965. The feasibility of growing greenhouse tomatoes in Southern Illinois, University of Illinois. Coop. Ext. Ser. Circular 914.

Cultivar	Values per acre
Willamette	$ 8,906 to $14,589
H. 1439	19,993 to 32,750
H. 1350	8,929 to 14,626
Fireball	8,376 to 13,725

By using Table 25 for value-per-acre estimates, the cost of baskets, hauling, and a 10 percent commission were subtracted from the price per basket before the above values were calculated. Therefore, the value per acre is slightly lower than when calculated on just wholesale prices.

Tomato plants of cultivars 'Michigan-Ohio, Hybrid' and 'Veegan' were seeded in flats about August 15, 1972, for the second greenhouse tomato crop. One hundred pounds N, 125 lb P_2O_5, and 100 lb K_2O were applied to the greenhouse soil as 16-20-0 and KCl and incorporated with a rototiller on September 13 and 14, 1972. After the greenhouse ground bed was prepared, it was covered with a plastic tarp and methylbromide was injected under the tarp at the rate of 1 lb per 100 ft^2 on September 19, 1972. The tarp was removed on September 22. Trellis supports for tomatoes were put in place on September 26. An additional ventilation fan and perforated plastic convection tube was installed inside the greenhouse on November 3, 1972, to aid air circulation.

A drip irrigation system was installed in the greenhouse on November 15. A "Twin-wall" hose from Chapin Watermatics, Inc., with orifices 8 in. apart was used. "Twin-wall" hose was placed beside each tomato row.

'Michigan-Ohio' and 'Veegan' were transplanted into the greenhouse on October 2, 1972. Tomatoes were placed in double rows 1 ft apart, and plants were 1 ft apart in the row. The double rows were on 5 ft centers. Two sets of double rows (14 plants per row) of each variety were included in half the greenhouse. Plant spacing was equivalent to about 15,000 plants per acre or about 2.9 ft^2 per plant. Tomatoes were 10 to 14 in.

tall when transplanted. One pint of 9-45-15 fertilizer mixed at the rate of 28 grams per gallon was applied to each plant after transplanting. Tomatoes were fertilized with KNO_3 and 9-45-15 in a liquid band application at 76, 148, and 217 lbs per acre of N, P_2O_5, and K_2O, respectively, on October 30, 1972.

Foliage damage that appeared to be "Early Blight" was noted on November 2, and "Maneb" was applied at the rate of 3 lbs per acre for control. Blossoms were open on both tomato cultivars by November 7, 1972.

Vegetative growth of tomato plants was good despite short days and low solar energy during October and November. The cool temperatures produced plants with thick, sturdy stems. Most day temperatures were adequate for growth and fruiting, but night temperatures during November and December were not sufficient for fruit production. The flower clusters were vibrated daily with an electrical vibrator to induce pollen to shed, but very few fruit developed because of the low night temperatures.

The record low temperatures in December 1972, described in the greenhouse lettuce section, damaged the tomato plants; they were removed from the greenhouse in December.

Japanese Salad and European Cucumber

Cucumbers are usually visualized as 8 to 9 in. long, about 2 in. in diameter, and with a fairly tough skin and seeds. Nearly all outdoor-grown cucumbers are of this type as are most of the greenhouse-grown cucumbers in this country. However, there has been increasing interest in production of seedless cucumbers in greenhouses. These cucumbers have grown in Europe for many years and are often referred to as European or Dutch. They are 12 to 18 in. long, seedless, mild, non-bitter, of high quality, and have a thin edible skin. Some Japanese cultivars are very similar in quality but have a rough skin. Some varieties are referred to as "burpless" cucumbers. Although the total production of the European types is not great, their production in Canada and the United States has increased substantially during the last 5 years.

Because the European-type cucumbers are so tender and thin-skinned, careful handling is essential. The fruits tend to wilt and break down more quickly than the shorter American types unless proper handling and storage conditions are provided. Some growers film-wrap each cucumber to reduce wilting and increase storage life.

These type cucumbers are not common in all areas of the United States and may not be immediately accepted on the local market until people become familiar with the commodity. For example, it was reported that European cucumbers produced in the Salt Lake area could not be marketed there, but had to be air freighted to the Los Angeles area where they were readily accepted.

The first cucumber type grown was a Japanese Salad type, 'Burpless F_1 Hybrid,' from the Robson Seed Company of Hall, New York. This variety was seeded in the greenhouse on February 17, 1972, and seedlings were transplanted to 12 x 40 in. spacings (3.3 ft^2/plant) on March 9, 1972.

Cucumber harvest started May 12, and fruit were picked when they reached 10 to 12 in. in length and about 2 in. in diameter. Cucumber yields reported in Table 26 are based on 13,200 plants per acre. About 30 percent of the crop was not classed as Nos. 1 or 2 fruit because of nonsymmetrical shape or oversize. A regular picking schedule was not maintained; this could have eliminated most fruit discarded because of oversize. Greenhouse production of 'Burpless F_1 Hybrid' cucumbers for a 5 month harvest period is given in Table 26. Yields included Nos. 1 and 2 cucumbers.

The cucumber plant spacing used in the project's greenhouse was closer than the 4 ft^2 per plant (10,890 plants/acre) suggested in "Greenhouse

Table 26. YIELD AND ESTIMATED VALUE OF JAPANESE SALAD CUCUMBERS (BURPLESS F_1 HYBRID) GROWN IN THE PROJECT'S SOIL HEATED GREENHOUSE AND HARVESTED FROM MAY 12 THROUGH SEPTEMBER 11, 1972.

		Yield/Acre				Estimated Value/Acre			
Plant Population	Sq. Ft. /Plant	Fruit Number	Fruit Wt-Tons	Avg No. Fruit/ Plant	Avg Fruit Wt-lbs	at avg 20¢/lb	at avg 35¢/lb	Based on $3.00/doz	Based on $4.00/doz
13,200[a]	3.3	643,950	391	48.7	1.21	$156,400	$273,700	$160,986	$214,648
10,000	4.3	489,402	297	48.7	1.21	$118,800	$207,900	$122,349	$163,132
8,000	5.4	392,809	238	48.7	1.21	$ 95,200	$166,600	$ 98,202	$130,936

[a] population used in greenhouse.

Table 27. COMPARISON OF NO. 1 GREENHOUSE CUCUMBER FRUIT YIELDS PRODUCED IN ONTARIO, CANADA ON STRAW BALES WITH CUCUMBER YIELD PRODUCED IN PROJECT'S GREENHOUSE.

Variety	Year	Harvest Period	Sq Ft/ Plant	Plants/ Acre	No. Fruit/ Plant	Avg Fruit/ Wt-Lbs	Wt Fruit/ Plant-Lbs	Tons/ Acre
Toska[a]	1970	Mar 9-Jul 6	9.2	4,752	32.5	1.36	44.1	117.6
Toska[a]	1970	Mar 9-Jul 6	7.5	5,808	36.6	1.35	49.4	128.4
Toska[a]	1970	Mar 23-Jul 13	8.5	5,124	30.6	1.30	39.7	101.8
Toska[a]	1972	Feb 11-Jul 13	9.6	4,537	35.1	1.36	47.7	108.2
-- --	-- --	-- -- --	-- --	-- --	-- -- --	-- -- --	-- -- --	-- --
Burpless Hybrid[b]	1972	May 12-Jul 25	3.3	13,200	30.5	1.20	36.9	170.5

[a] Grown on straw bales in Ontario, Canada.

[b] Grown in soil heated ground bed in project's greenhouse.

Vegetable Production in Ontario"[48] and the 9.6 ft^2 per plant (4,537 plants/acre) used in European cucumber trials in Harrow, Ontario, in 1972.[49] Yields of European-type cucumbers ranged from 15 to 25 lb per plant[50] to 49.4 lb per plant.[49] The high yield in Ontario's trials was produced by cultivar 'Toska' with straw bale culture and 7.5 ft^2 per plant (Table 27). The average yield per plant of 'Burpless F_1 Hybrid' was 48.7 lb (Table 26).

Cucumbers in the project's greenhouse were harvested longer than in the Canadian trials and there were more plants per acre in the project house. Therefore, the cucumber yields produced per acre were considerably higher in the project greenhouse than in the Canadian trials. Table 27 was included to show that yields of European cucumbers produced in the project's greenhouse were in line with yields obtained in other areas when harvest period and plant populations are taken into consideration.

The season in which cucumbers are planted will probably influence plant populations that can be used. More plants per acre can be used in a spring-summer crop than for a winter crop because of greater light intensity in the spring months. Local environment will also influence plant populations that can be used. The plant population used in this first planting of cucumbers may have to be reduced in a large scale planting. Reducing plant number per acre would probably reduce yields and values indicated in Table 26 for the 13,200 plants per acre. Estimated values for plant populations of 10,000 and 8,000 plants per acre are also given in Table 26. It was assumed that the number of fruit and fruit weight per plant would not be lower than was produced with 13,200 plants per acre.

Jensen[51] reported wholesale prices ranging from 20¢ to 40¢ for European cucumbers. European cucumbers grown in Washington State are sold in boxes of 12, and the grower reportedly receives from about $4.00 to $4.25 per box. These prices were taken into consideration in Table 26 in estimating the value of the Japanese Salad cucumber crop. The value of the crop could range from about $95 to $273 thousand per acre. These cucumbers are still a specialty item and impact of large acreages could affect prices received for the crop.

A second crop of European (cv. Toska) and Japanese (cv. Burpless F_1 Hybrid) cucumbers was planted in the greenhouse on October 3, 1972, on 48 x 18 in. spacings. Plants emerged October 10. By November 2, cucumber seedlings were 2 to 3 in. tall. Cool greenhouse temperatures were not ideal for good cucumber growth, and the plants were removed after the cold December period described in the lettuce section.

SECTION VII

MOLD COUNT, BACTERIA, AND MYCOTOXIN STUDY

Studies were conducted in cooperation with Dr. George Pigott to determine if crops grown under different irrigation and/or soil heating conditions would influence levels of mold, bacteria, or mycotoxins.

The objective of the study was to compare safety of raw crops grown under four different conditions on the thermal irrigation test farm.

The samples were picked 4:00 to 4:30 p.m., August 15, 1972, at the Project's test plots and delivered to Schick Laboratories at 9:30 p.m. The samples were placed in a refrigerator at 9:50 p.m. and analyses was started the next morning at 8:00 a.m.

The following is a description of how the samples were grown:

Beets

Soil heat	Cold water
Soil heat	Warm water
No soil heat	Cold water
No soil heat	Warm water

Beans

Soil heat	Cold water
Soil heat	Warm water
No soil heat	Cold water
No soil heat	Warm water

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'Willamette' Tomatoes

Soil heat	No mulch
No soil heat	No mulch
Soil heat	Black plastic mulch
No soil heat	Black plastic mulch

'Fireball' Tomatoes

Soil heat	No mulch
No soil heat	No mulch
Soil heat	Black plastic mulch
No soil heat	Black plastic mulch

Each sample (200-300g) was homogenized in a high speed blender from which aliquots were taken for analysis. Aliquots of each homogenate were used for determination of aerobic plate count, most probably number of coliforms and Escherichia Coli.* A second aliquot was used for culture of yeast and molds in Sabouraud's medium. A 100 gram aliquot was extracted with a chloroform-methanol mixture for aflotoxin and ochratoxin assays.+

Samples of homogenate were frozen for moisture and protein nitrogen determination.‡ Initial results are outlined in Tables 28, 29, and 30.

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*Microbiological Methods used are described in: Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC), Eleventh Edition, 1970. pp. 839-852.

+Aflotoxin and Ochratoxins were determined by thin layer chromatography of Chloroform-Methanol extracts: Fishbein, L. and Falk, H. L. 1970. Chromatography of Mold Metabolites, I. Aflotoxins, Ochratoxins and related compounds. Chromatog. Rev. 12: 42-87.

‡Moisture and protein nitrogen. AOAC, 11th ed., 1970, pages 272 and 16-17.

Table 28. MICROBIOLOGICAL RESULTS OF AEROBIC PLATE COUNT, COLIFORMS, E. COLI, AND STAPHYLOCOCCUS COUNTS MADE ON SELECTED VEGETABLES GROWN UNDER DIFFERENT IRRIGATION AND/OR SOIL HEATING CONDITIONS

Vegetable	Treatment	Total Aerobic Count/gm	Total Coliforms	E. Coli	Staph.
Beets	soil neat-cold water	1200	1	0	0
	soil heat-warm water	800	0	0	0
	no soil heat-cold water	500	2	0	0
	no soil heat-warm water	700	0	0	0
Beans	soil heat-cold water	700	2	0	0
	soil heat-warm water	500	1	0	0
	no soil heat-cold water	600	0	0	0
	no soil heat-warm water	900	2	0	0
Variety- Willamette Tomatoes	soil heat-no mulch	600	2	0	0
	no soil heat-no mulch	900	0	0	0
	soil heat-black plastic mulch	400	0	0	0
	no soil heat-black plastic mulch	600	0	0	0
Variety- Fireball Tomatoes	soil heat-no mulch	600	2	0	0
	no soil heat-no mulch	500	0	0	0
	soil heat-black plastic mulch	700	3	0	0
	no soil heat-black plastic mulch	600	0	0	0

Table 29. MOLD COUNTS OBTAINED ON SABOURAUD'S MEDIUM FROM SELECTED VEGETABLES GROWN UNDER DIFFERENT IRRIGATION AND/OR SOIL HEAT CONDITIONS.

Vegetable	Treatments	Colonies/gm
Beets	soil heat-cold water	5
	soil heat-warm water	10
	no soil heat-cold water	4
	no soil heat-warm water	6
Beans	soil heat-cold water	15
	soil heat-warm water	4
	no soil heat-cold water	8
	no soil heat-warm water	10
Variety- Willamette Tomatoes	soil heat-no mulch	10
	no soil heat-no mulch	15
	soil heat-black plastic mulch	10
	no soil heat-black plastic mulch	4
Variety- Fireball Tomatoes	soil heat-no mulch	16
	no soil heat-no mulch	20
	soil heat-black plastic mulch	20
	no soil heat-black plastic mulch	14

Table 30. PROTEIN AND MOISTURE ASSAYS OF VEGETABLES GROWN UNDER DIFFERENT IRRIGATION AND/OR SOIL HEAT CONDITIONS

Vegetables	Treatment	Moisture %	Protein %
Beets	soil heat-cold water	85.5	1.56
	soil heat-warm water	84.2	1.48
	no soil heat-cold water	86.3	1.57
	no soil heat-warm water	84.8	1.58
Beans	soil heat-cold water	90.1	2.20
	soil heat-warm water	88.9	2.15
	no soil heat-cold water	89.5	2.14
	no soil heat-warm water	89.2	2.10
Variety- Willamette Tomatoes	soil heat-no mulch	94.2	0.91
	no soil heat-no mulch	95.1	0.92
	soil heat-black plastic mulch	95.0	0.90
	no soil heat-black plastic mulch	93.7	0.93
Variety- Fireball Tomatoes	soil heat-no mulch	95.4	0.95
	no soil heat-no mulch	95.2	0.94
	soil heat-black plastic mulch	94.6	0.89
	no soil heat-black plastic mulch	95.6	0.96

Gram stains were made of the principal colonies in order to identify them. Principal organisms were aerobacter, aerogenes, and bacillus subtilis. Examination of the molds showed that Aspergillus niger and Rhizopus nigricans were the principal molds.

One hundred gram aliquots were used for aflotoxin and ochratoxin assays. All 16 samples were negative for either aflotoxin, which are toxic mold metabolites.

Regardless of the conditions under which the crop was grown, there was no difference in the microbiological results, total mold counts, or the general type of organism found under the four different conditions for these particular vegetables. There was no toxic mold metabolites as determined by the absence of aflotoxins and ochratoxins in all 16 samples.

The nutritive quality of the vegetables grown under four different conditions are the same as reflected by the similarity of the protein nitrogen values and total moisture in the four samples for each vegetable.

It appears that the vegetables are safe and wholesome as indicated by the low bacteria and mold counts in addition to the absences of E. coli and staphylococcal organisms. Further, the absence of mycotoxins (aflotoxins and ochratoxins) confirm safety from mold contamination or abnormal mold flora.

The protein nitrogen values and moisture content for each vegetable, some grown under four different conditions, show no variations and are in good agreement with published results.

Increased soil heat or the use of thermal water had absolutely no effect on the mold or bacterial populations normally used as an indicator.

SECTION VIII

SOIL HEAT/IRRIGATION

PLOT DESCRIPTION

An area 216 ft long by 218 ft wide was used for this experiment. An area 120 ft by 216 ft was over the soil heating pipes. On each side was an area with no soil heat. The total area was divided into 4 replications. Each replication was divided into 4 plots; each plot measured about 2400 sq ft and had the same crops but with a different combination of treatments. Treatments included soil heat vs no soil heat and cold water irrigation vs thermal water irrigation. Each replication had 2 plots off soil heat and 2 plots on soil heat. Separating the plots north and south (at right angles to the soil heat area) were 2 rows of sweet corn cv. Jubilee. This served as a barrier between the cold water irrigation and thermal water irrigation treatments.

Irrigation pipe was laid along each side of the plot beside and parallel to the corn rows. Rain Bird 25A sprinklers with 3/32 in. nozzles were spaced on 40 ft centers giving an overall spacing of 40 ft x 40 ft. Sprinklers were set for 180° rotation so only the plot area between corn rows would be irrigated with a particular irrigation treatment, cold or thermal water.

PROCEDURE

The following information applies to the entire area and any additional details that apply to one particular crop will be covered in the discussion of individual crops.

On May 20, 1972, fertilizer was applied in band form down the center of each bed. Row centers were 4 ft apart. Fertilizers included 600 lbs

16-20-0 per acre, 400 lbs treble super phosphate per acre, and 83 lbs muriate of potash per acre. Granular "Diazinon" insecticide was applied in the same manner at the rate of 4 lbs active material per acre. This rate was used for control of wireworms as suggested in the 1971 Oregon Insect Control Handbook. Following application of the fertilizer and insecticide, it was incorporated into the soil by rototilling.

In each plot, there were 9 different crops planted. Each crop, except tomatoes, was planted in three 20 ft long rows spaced 4 ft apart. There was only one row of each variety of tomato planted instead of the 3 rows of each of the other crops. Two rows of variety 'C. 1327' were planted in Reps II and IV instead of 1 row 'C. 1327' and 1 row 'H. 1350' due to short supply of variety 'H. 1350.'

Crops were:

bush beans	Blue Lake 274
tomato	New Yorker, C. 1327, & H. 1350
pepper	Calwonder
cabbage	Golden Acre
onion	Yellow Globe Danvers
lima (baby)	Thaxter
beets	Detroit Dark Red
celery	Utah #15
cucumber	Pioneer

Bush beans, limas, onions, celery, cucumbers, peppers, and tomatoes were planted with a Planet-Jr. on May 25.

On May 26, the red beets were planted; the cabbage was planted June 5. A Panet-Jr. seeder was used for both crops.

The celery seed did not germinate properly so there was no celery crop to harvest. Shortly after the other crops began to emerge, flea beetles and cucumber beetles began doing some damage to certain of the seedlings. On June 21, all crops were sprayed with the insecticide Sevin 50 W at a rate of 1 lb active material per acre, mixed at rate of 100 gals water per acre.

Tensiometers were placed at several locations in rows of peppers both on and off soil heat. Each location included three tensiometers, at depths of 6, 12, and 18 in. Readings were taken regularly (Figure 65) and were used to aid in the scheduling of irrigations.

When irrigations were made, cold well water (50-55°F) and thermal water (98-118°F) were applied at the same time and quantities (Table 31).

Tomatoes and cucumber seedlings were thinned on June 28. The tomatoes were at approximately the 4th to 5th true leaf stage and were thinned to a spacing of one to two plants per 12 in. of row.

The crops were again sprayed with Sevin 50 W at the rate of 1 lb active material per acre on July 4. Spraying was primarily for the control of flea beetles and cucumber beetles. A few hornworms were noted on some of the tomato plants but populations and damage were not great enough to merit a special spray program for their control.

Weeding of the area was done by pulling or hoeing. No herbicides were used due to the many varieties of crops grown in a small area.

On July 17, cabbage plants were thinned to 15 in. apart; they were 5 to 7 in. tall and had five to six true leaves at thinning. The peppers were thinned the same day at the same spacing as the cabbage (15 in. apart); they were 4 to 5 in. tall and at the four to five true leaf stage.

Several root maggots were observed on some of the young cabbage plants; however, the problem wasn't severe enough to warrant a special spray program.

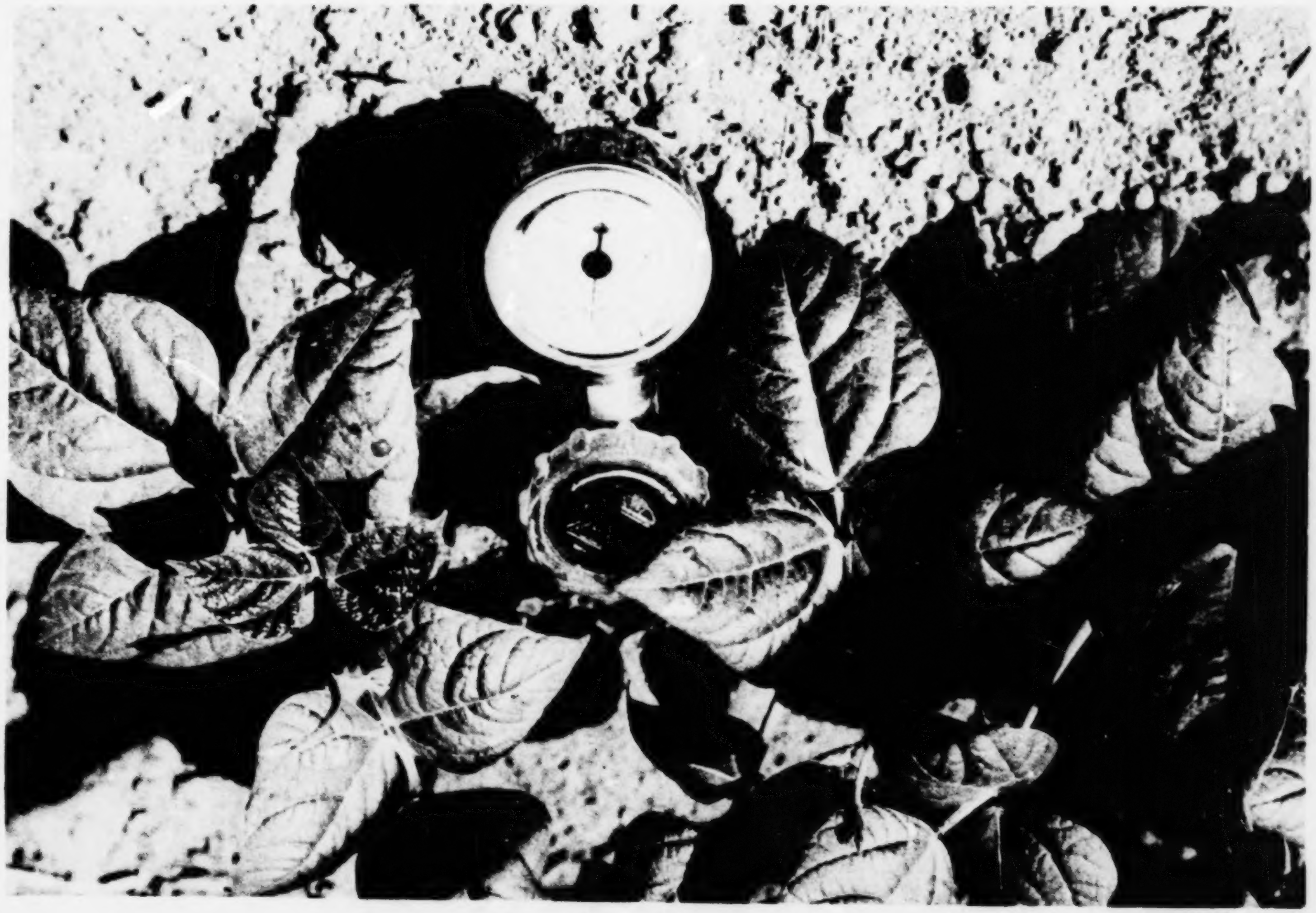

Figure 65: Tensiometer

Table 31. PRECIPITATION AND IRRIGATION, BOTH THERMAL AND COLD WATER, APPLIED (INCHES) TO PLOTS DURING JUNE, JULY, AND AUGUST.

June 2	.55	July 8	.55
7	.08[a]	8	.06[a]
8	.49[a]	14	1.10
9	.68[a]	29	1.50
10	.59[a]	August 9	2.00
11	.05[a]	14	.02[a]
15	.02[a]	16	1.41[a]
22	1.00	20	.27[a]
29	1.20	29	1.50

Values followed by [a] were rainfall, others were irrigation applications.

Two more sprayings of the crops with Sevin 50 W were carried out (July 7 and August 3) during the rest of the growing season. The insecticide was applied at the rate of 1 lb active material per acre, but instead of mixing it with 100 gal water, it was concentrated to 1 lb active material per 20 gal water per acre.

On August 16 and 17, foliar samples were taken from several of the crops and analyzed for N, P, K, Ca, Mg, Zm, and Mn. Samples consisted of:

> Table beets--Petiole of mature leaf, not from leaves that were very old or showed signs of drying
>
> Onions--Mature leaf but not those that were dried
>
> Peppers--4th mature leaf down from tip of plant
>
> Lima beans--4th trifoliate leaf
>
> Cabbage--Mid-rib of wrapper leaf

Cucumbers

A 10 ft section of one row in each plot was harvested seven times during the period July 26 to September 7. After each harvest, the cucumbers from each plot were counted, weighed, and graded into six classes--Nos. 1, 2, 3, over 3, crooks, and nubs and culls.

Snap Beans

Two harvests were made of a 5 ft section from one row in each plot. The plants from the 5 ft section were pulled and all the beans were taken at each harvest. This simulated a typical machine harvesting operation. The beans were taken immediately to Oregon State University and run through a commercial-type bean grader. Beans were graded out into five classes and each was weighed separately. Classes (according to seive size) were as follows: 1-2, 3, 4, 5, and 6-7. The harvest dates were July 31 and August 2, 1972.

Cabbage

Cabbage was harvested on two dates as the heads became mature--August 24 and September 11, 1972. The heads from a 15 ft section of one row in each plot were harvested, counted, and weighed. A grading system was not used.

Peppers

Peppers were harvested on September 18 and November 8, 1972; a 10 ft section was taken from one row in each plot. Harvested fruit were weighed, counted, and graded in classes of U.S. Fancy, No. 1, No. 2, and culls.

Tomatoes

On August 26 the tomatoes were sprayed with the fungicide Maneb. It was applied at the rate of 3 lb Maneb, mixed in 20 gal water per acre. It was applied for the control of Early Blight. There were three harvests of the variety 'New Yorker'--September 20, October 6, and October 27, 1972. Varieties 'H. 1350' and 'C. 1327' were harvested only two times, October 6 and October 27, 1972. A 10 ft section of each variety in each plot was harvested. Fruit from each plot were weighed, counted, and classed as U.S. No. 1 and No. 2 canning and culls.

Lima Beans

A 10 ft section from each plot was harvested on September 22, 1972. The beans from each plot were shelled and weighed. Grading was not done.

Onions

On October 4, 1972, a 10 ft section of one row of onions in each plot was harvested, weighed, counted, and graded into three classes: U.S. No. 1, No. 2, and culls.

TABULAR DATA: SOIL HEAT/IRRIGATION

Table

32. Nutrient Levels (Dry wt Basis) of Selected Vegetable Crops from Soil Heated and Control Blocks

33. Effect of Soil Heat on Yield of 'Thaxter' Lima Beans

34. Effect of Heated Soil on Yield of Table Beet, cv. Detroit Dark Red

35. Influence of Heated Soil and Thermal Irrigation on Yield of Snap Beans, cv. Bush Blue Lake 274, on Two Harvest Dates

36 Effect of Soil Heat on Yield and Grade of Tomato cvs. H. 1350, C. 1327, and New Yorker

37. Effect of Soil Heat on Yield and Grade of Pickling Cucumber, cv. Pioneer Hybrid

38. Effect of Soil Heat on Grade and Yield of Onions, cv. Danvers Yellow Globe

39. Effect of Soil Heat on Yield 'Golden Acre' Cabbage

Table 32. NUTRIENT LEVELS (DRY WT BASIS) OF SELECTED VEGETABLE CROPS FROM SOIL HEATED AND CONTROL BLOCKS.

(SAMPLES TAKEN AUGUST 16 and 17, 1972).

OREGON STATE UNIVERSITY

	BEETS[t]		ONIONS[u]		SNAPBEANS[v]		PEPPERS[w]		LIMA BEANS[x]		CABBAGE[y]		SWEET CORN[z]	
Total	Soil heat	Control	Soil heat	Control	Soil heat	Control	Soil heat	Control	Soil heat	Control	Soil heat	Control	Soil heat	Control
N (%)	2.77	2.78	4.68	4.62	5.09	5.06	5.79	5.69	5.02	4.21	4.11	4.23	3.52	3.33
P (%)	0.49	0.51	0.41	0.43	0.47	0.44	0.46	0.42	0.34	0.33	0.68	0.69	.42	0.33
K (%)	5.66	6.46	3.32	3.76	3.42	3.42	4.99	4.89	2.49	2.42	4.12	4.66	2.68	2.57
Ca (%)	0.07	0.07	0.17	0.16	0.23	0.19	0.19	0.19	0.36	0.30	0.23	0.22	.08	0.07
Mg (%)	1.27	1.20	0.55	0.49	0.67	0.62	1.00	0.97	0.70	0.63	0.49	0.49	.26	0.33
Zn (ppm)	30	36	25	28	45	39	112	105	42	75	42	39	41	42
Mn (ppm)	95	90	72	100	93	90	263	242	100	144	70	69	77	61

Samples consisted of:

t petiole of mature, but not old leaf

u mature leaf-taken before drying starts

v 4th trifoliate leaf

w 4th mature leaf down from tip

x 4th trifoliate leaf

y midrib of wrapper leaf

z midrib from center section of mature leaf

Table 33. EFFECT OF SOIL HEAT ON YIELD OF 'THAXTER' LIMA BEANS.^{z}

	Lbs/10 ft plot		
Treatment	Fresh plant wt	Fresh pod and bean wt	Ungraded shelled bean wt
Soil heat	10.3a	10.3a	4.1a
Control	7.4b	8.9a	3.2b

^{z}Means within a column followed by different letter differ significantly at 5% level; means followed by same letter are not significantly different.

Table 34. EFFECT OF HEATED SOIL ON YIELD OF TABLE BEET, CV. DETROIT DARK RED[z]

Treatment	Lbs/acre Larger than 1-1/2 in. dia	Lbs/acre Smaller than 1-1/2 in. dia
Soil heat	623a	8389a
Control	431b	9150a

[z] Means followed by different letters significantly different at 1% level.

Table 35. INFLUENCE OF HEATED SOIL AND THERMAL IRRIGATION ON YIELD OF SNAP BEANS, CV. BUSH BLUE LAKE 274, ON TWO HARVEST DATES

July 31, 1972, Harvest

Treatments	Avg No. plants/ft row	Yield tons/acre	% seive size distribution 1-4	5	6-7
Soil heat	7.3	4.0	80	10	10
Control	7.2	4.4	75	25	0

August 2, 1972, Harvest

Treatments	Avg No. plants/ft row	Yield tons/acre^z	% seive size distribution 1-4	5	6-7
Soil heat	7.2	8.7a	45	40	15
Control	6.6	4.8b	60	30	10

---

[z] Means followed by different letters significantly different at 1% level.

Table 36. EFFECT OF SOIL HEAT ON YIELD AND GRADE OF TOMATO CVS. H 1350, C. 1327, AND NEW YORKER[z]

H. 1350

	Fresh wt in tons/acre				
Treatment	No. 1	No. 2	Green	Culls	Total
Soil heat	5.5a	13.7	21.7	20.8	61.7
Control	11.7b	15.5	20.6	36.8	34.6

C. 1327

	Fresh wt in tons/acre				
	No. 1	No. 2	Green	Culls	Total
Soil heat	7.6	13.7	18.1	26.6	66.0
Control	7.2	15.1	18.3	19.5	60.1

New Yorker

	Fresh wt in tons/acre				
	No. 1	No. 2	Green	Culls	Total
Soil heat	17.3	24.5	5.4	18.7	66.0
Control	16.8	20.8	4.2	15.6	57.4

---

[z] Means within a column in each series followed by different letters differ significantly at 5% level; other means nonsignificantly different.

Table 37. EFFECT OF SOIL HEAT ON YIELD AND GRADE[x] OF PICKLING CUCUMBER, CV. PIONEER HYBRID.[z]

	Tons Cucumbers/avg				
	No. 1	No. 2	No. 3	d Nubs	Culls
Soil heat	3.2a	12.1a	9.1a	10.9a	3.5a
Control	3.6b	15.2b	11.9b	10.3a	2.7a

[x] Grades based on diameter: No. 1 (under 1 in. dia), No. 2 (1 to 1-1/2 in. dia), No. 3 (1-1/2 to 2 in. dia).

[z] Means within a column followed by different letters differ significantly at the 5% level.

Table 38. EFFECT OF SOIL HEAT ON GRADE AND YIELD OF ONIONS, CV. DANVERS YELLOW GLOBE

	lbs/acre		
	U.S. No. 1	U.S. No. 2	Culls
Soil heat	12660	1231	48
Control	12712	1343	464

Table 39. EFFECT OF SOIL HEAT ON YIELD 'GOLDEN ACRE' CABBAGE

	cwt/acre
Soil heat	253
Control	284

SECTION IX

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SECTION X

APPENDICES

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TABLE A-1

ANNUAL COST/ACRE FOR CROP PROTECTION AND IRRIGATION

System	Frost Protection (Per Acre Per Year)	Irrigation (Per Acre Per Year)	Plant Cooling (Per Acre Per Year)	Total Annual Fixed Cost (Per Acre Per Year)
Multi-use	—	—	—	$82.81
Solid Fuel Plus Irrigation	—	$20.385(1)	Not Possible	20.385
Central Distribution	$71.347(1)	20.385(1)	Not Possible	91.732

(1) Based upon a capital recovery factor of 0.1359 (10-year amortization at 6% interest)

TABLE A-2

ANNUAL OPERATIONAL COST FOR CROP PROTECTION AND IRRIGATION SYSTEM

System Cost Factor/Acre	Multi-use	Solid Fuel & Hand-Moved Irrigation Cost per Acre	Central Distribution & Hand-Moved Irriga. Cost per Acre
Frost Protection	$ 1.16	$250.00	$280.00
Power/Fuel	1.80	2.57	2.57
Irrigation & Plant Cooling			
Power	4.64	3.48	3.48
Labor	3.60	9.00	9.00
TOTAL ANNUAL COST/ACRE	$11.20	$265.00	$295.00

TABLE A-3

TOTAL ANNUAL COST PER ACRE FOR THREE CROP PROTECTION AND IRRIGATION SYSTEMS

System	Annual Fixed Cost	Annual Operational Cost per Acre	Total Annual Cost
Multi-Use	$82.81	$ 11.20	$ 92.74
Solid Fuel & Hand-Move Irrigation	20.385	265.05	285.435
Central Distribution & Hand-Move Irrigation	91.732	295.05	386.782

TABLE A-4

Calculations for annual operational costs/acre for crop protection and irrigation.

A. Multi-use System

1. Frost Protection:

   a) Power cost[1] =

$$= \frac{\text{Annual Pumping (lbs } H_2O) \times \text{total head (ft)}}{1{,}980{,}000\ \dfrac{\frac{\text{ft-lbs}}{\text{H}}}{\text{hp}} \times 1.34\ \frac{\text{hp}}{\text{KW}} \times \text{efficiency}} \times \frac{\$}{\text{KWH}}$$

$$= \frac{75{,}751{,}200 \times 170}{1{,}980{,}000 \times 1.34 \times .60} \times .01 = \$80.89\text{/orchard}$$

(or)

$$\frac{80.80}{70} = \$1.16\text{/acre}$$

   Annual pumping = 54 gpm/acre x 70 acres x 60 min/hr x 40 hrs x 8.35 lbs/gal = 75,751,200 lbs water

   Overall efficiency = 60%

   Total head = 170 ft

   b) Labor cost = assuming time is equal to that required for one complete irrigation with a hand-move system as in Part B2 = 0.9 man hrs/acre x $2.00/man hr = $1.80/acre

2. Irrigation and Plant Cooling:

   a) Power cost — same formula as above

   Assuming five 24 hr irrigation and ten 4 hr plant cooling periods during the summer season at 54 gpm = $4.64/acre

   b) Labor cost — assuming time is equal to that required for two complete irrigations with a hand-move system as in Part B2 = 0.9 x $2.00 x 2 irrigations — $3.60

B. Solid Fuel & Hand-Move Irrigation System

1. Frost Protection:

   a) Fuel — $50.00 worth of material/night x 5 nights = $250.00[2]

   b) Labor — assuming 6 men are needed for 3 hrs/night/70 acre orchard
   6 men x 3 hrs/night x 5 nights x $2.00/man hr x 1/70 acres = $2.57/acre

2. Irrigation:

   a) Power — same as for irrigation in Part A, rate of application of water only differs = $3.48/acre

   b) Labor[1] — 0.9 man hrs/acre/irrigation
   Assuming labor at $2.00/hr and 5 irrigations/season
   0.9 man hrs/acre/irrigation x 5 irrigations/$2.00/man hr = $9.00/acre

C. Central Distribution & Hand-Move Irrigation System

1. Frost Protection:

   a) Fuel[3] — 40 heaters/acre x 1 gal/heater/hr x 40 hrs x 17.5¢/gal = $280.00/acre

   b) Labor — assuming 6 men are required for 3 hrs each night for a 70 acre orchard[4]
   6 men x 3 hrs x 5 nights x $2.00/man hr x 1/70 acres = $2.57/acre

2. Irrigation

   a) Power — same as Part B = $3.48/acre

   b) Labor — same as Part B = $9.00/acre

---

[1] Jensen (1966) listed in Reference Section

[2] From information in advertisements and articles in February, 1968 and February, 1971 American Fruit Grower, Western Edition

[3] Anon., 1968 — listed in Reference Section

[4] Anon., 1968 — listed in Reference Section

TABLE A-5

ITEM		DOLLARS/SQ FT	
Materials for framework		$0.222	
Labor to erect framework and attach film		0.082	
Plastic film (UV "Poly")		0.029	
Structure Sub-total			$0.333
Thermal water heating & ventilation system		0.492	
Electric Wiring		0.038	
Environmental Control Sub-total			0.530
	Bal. Fwd.		
Irrigation System		0.078	0.078
Contingency Factor (20%)		0.188	0.188
	TOTAL COST/SQ FT		$1.129

TABLE A-6

CROP VALUE USING WHOLESALE PRICE IN PORTLAND, OR

Harvest Date	Type of Produce	Min/Price/Acre	Max/Price/Acre
April 24, 1972	Lettuce--Grand Rapids	$ 5,437	$ 8,192
	Lettuce--Bibb	8,478	15,109
July 14- Sept. 12, 1972	Tomatoes--H.1439	27,693	37,424
	--H.1350	13,311	15,104
	Fireball	12,587	14,283
	Willamette	11,788	13,376
May 12- Sept. 11, 1972	Japanese Salad Cucumbers	156,400	273,700

TABLE A-7

SELECTED CROPS--MINIMUM RETURN $ (1972)

Crop	Price per Acre
Lettuce--Grand Rapids	$ 5,437
Tomatoes--H.1439 (See comments on xxxii)	
Japanese Salad Cucumbers	156,400
Gross Return	$161,837

SELECTED CROPS--MAXIMUM RETURN $ (1972)

Crop	Price per Acre
Lettuce--"Bibb"	$ 15,109
Tomatoes--H.1439 (See comments on xxxii)	
Japanese Salad Cucumbers	273,700
Gross Return	$288,809

TOM McCALL
GOVERNOR

OFFICE OF THE GOVERNOR
STATE CAPITOL
SALEM 97310

JUN 11 9 06 AM '73

June 7, 1973

Mr. Byron Price
General Manager
Eugene Water & Electric Board
P. O. Box 10148
Eugene, Oregon 97401

Dear Byron:

I take this opportunity to congratulate you and the Eugene Water & Electric Board for a significant research effort in your warm water studies.

The Springfield warm water demonstration project pioneered by the Eugene Water & Electric Board has proved the value of warm industrial waste water for agricultural uses.

This project utilizing warm water for frost protection, soil heating and irrigation will have far-reaching effects on future agri-nuclear projects.

The information gained by this endeavor will encourage close cooperation between the power industry and agriculture in developing nuclear thermal power plants in conjunction with agricultural irrigation projects.

Your pioneering efforts in the field of warm water utilization will have far-reaching benefits to the economy of Oregon.

Sincerely,

Tom
Governor

TM:cs

CECIL D. ANDRUS
GOVERNOR

IDAHO NUCLEAR ENERGY COMMISSION
DONALD J. MACKAY, CHAIRMAN -- IDAHO FALLS
ALBERT E. WILSON, VICE CHAIRMAN -- POCATELLO
EUGENE F. BERRY -- BLACKFOOT
ROBERT M. BRUGGER -- IDAHO FALLS

IDAHO NUCLEAR ENERGY COMMISSION

STATE OF IDAHO
OFFICE OF
NUCLEAR ENERGY DEVELOPMENT

GENE P. RUTLEDGE
EXECUTIVE DIRECTOR

STATEHOUSE
BOISE, IDAHO 83707

P. O. BOX 2234
IDAHO FALLS, IDAHO 83401
TELEPHONE 208 - 523-2586

MAY 29 8 41 AM '73

May 21, 1973

Mr. Byron Price, General Manager
Eugene Water and Electric Board
P. O. Box 1112
Eugene, Oregon 97401

Dear Byron:

It certainly was a pleasure to see you in Boise a few days ago at the Energy Symposium sponsored by our University of Idaho.

During this session it became more and more apparent that our energy needs are going to climb swiftly in the near future and that the amount of reject (or waste) heat will also get greater and greater.

I would like to commend you for your effort on the agricultural utilization of hot water from the industrial plant near Springfield, Oregon. Our office is trying to do something similar in Idaho, albeit on a much more modest scale. Therefore, I plan to read the final report of your thermal water demonstration project in detail.

I hope that more people will follow your lead in an effort to utilize the potential energy that is tied up in our industrial and nuclear thermal effluents.

Yours truly,

Gene

Gene P. Rutledge
Executive Director

GPRem

WESTERN INTERSTATE NUCLEAR BOARD
P.O. BOX 15038 • LAKEWOOD, COLORADO 80215 • (303) 238-8383

DR. ALFRED T. WHATLEY
Executive Director

RECEIVED
EUGENE WATER
& ELECTRIC BOARD
MAY 17 7 41 AM '73

May 9, 1973

Mr. Byron Price, General Manager
Eugene Water and Electric Board
P. O. BOX 1112
Eugene, Oregon 97401

Dear Mr. Price:

Our Western Interstate Nuclear Board is very interested in the meaningful utilization of warm water from industrial (especially nuclear) plants. This interest in our WINB has been so strong that we formed a Thermal Effluents Application Committee which is addressing itself to the utilization of these low grade BTU's.

As it now stands, our projects that are underway will utilize the information that you have gained during your Thermal Water Demonstration Project near Springfield, Oregon.

Your interium progress reports have been very valuable to us, and we are anxious to study your final report.

Our Western Interstate Nuclear Board appreciates the many considerations that you have shown to our board representatives. We also express our pleasure at the foresight that you and your associates have shown.

Yours truly,

Donald C. Gilbert

Donald C. Gilbert
Chairman
Western Interstate Nuclear Board

DCG/cm

GENERAL LABORATORY REPORT

Sample Source: Weyerhaeuser Corporation
Springfield, Oregon
No: A-105-1
Date: September 5, 1968
Material: Cooling Water
By: Vitro Corporation

Physical Properties

General Appearance: Clear

Odor: None

Analysis

pH	6.8
P Alkalinity	0.0 ppm
M Alkalinity	37.0 ppm
Total Solids	86.0 ppm
Suspended Solids	Trace
Dissolved Solids	86.0 ppm
Calcium as Ca	6.4 ppm
Magnesium as Mg	3.8 ppm
Sodium as Na	4.6 ppm
Iron as Fe	0.05 ppm
Phosphate as PO_4	0.0 ppm
Chloride as Cl	3.6 ppm

Signature Lee Henry
Date 9-13-68

WATER TREATMENT CORP. OF AMERICA - 2852 N. W. 31st Ave., Portland, Ore. - Phone (503) 226-1451

GENERAL LABORATORY REPORT

Sample Source: VITRO CORPORATION OF AMERICA
2284 Oakmont Way
Eugene, Oregon 97402
ATTN: Mr. Colin Nilsson

No: A-212-2

Date: 8-25-69

Material: Weyerhaeuser Cooling Water

By: Vitro Corporation

Physical Properties

General Appearance: Clear

Odor: None

Analysis

pH	7.1
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	29.0
Total Solids	71.0
Suspended Solids	8.0
Dissolved Solids	63.0
Calcium as Ca	4.0
Magnesium as Mg	2.2
Sodium as Na	3.8
Iron as Fe	0.1
Phosphate as PO_4	0.0
Chloride as Cl	1.6

NOTE: The above results are reported in mg/l (ppm) with the exception of pH

Signature ____________________

(215) **Date** 9-4-69

WATER TREATMENT CORP. OF AMERICA - 2852 N.W. 31st Ave., Portland, Ore. - Phone (503) 226-1451

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

EXECUTIVE OFFICES • 20600 CHAGRIN BLVD. • CLEVELAND, OHIO 44122

Reply to:
Watcos Division
2652 N. W. 31st Avenue
Portland, Oregon 87210

June 15, 1970

Mr. Dick Tipton
Vitro Hanford Engineering Services
2284 Oakmont Way
Eugene, Oregon 97401

LABORATORY REFERENCE NO. : A-314-A, A-314-B

Dear Mr. Tipton:

The following information summarizes the results we obtained from the McKenzie River water and the pumping pit samples we received in our laboratories on June 11, 1970.

McKENZIE RIVER WATER ANALYSIS

pH	7.2
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	30.0
Total Solids	19.0
Suspended Solids	3.0
Dissolved Solids	16.0
Calcium as Ca	3.5
Magnesium as Mg	2.0
Sodium as Na	3.7
Iron as Fe	1.0
Phosphate as PO_4	1.27
Chloride as Cl	0.9

Plants
Chagrin Falls, Ohio
Charlotte, North Carolina
Arlington, Texas
Phoenix, Arizona

Canada
Continental Chemicals, Ltd.
Winnipeg, Manitoba

Australia
The Nightingale Supply Co., Ltd.
Sydney, N.S.W.

PUMPING PIT ANALYSIS

pH	6.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	36.0
Total Solids	30.0
Suspended Solids	3.0
Dissolved Solids	27.0
Calcium as Ca	5.3
Magnesium as Mg	3.5
Sodium as Na	4.7
Iron as Fe	1.5
Phosphate as PO_4	0.67
Chloride as Cl	1.7

NOTE: All above results are reported in milligrams per liter, except pH.

If we can be of further assistance to you concerning the analyses or evaluation of the data, please ask.

Sincerely,

Lee Henry

Lee Henry
Director of Laboratories

LH/ejl

OCT 22 1970

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

EXECUTIVE OFFICES • 20600 CHAGRIN BLVD. • CLEVELAND, OHIO 44122

Reply to:
Northwest Division
2862 N. W. 31st Avenue
Portland, Oregon 97210

October 21, 1970

Vitro Hanford Engineering Services
2284 Oakmond Way
Eugene, Oregon 97401

Attention: Mr. Dick Tipton

Laboratory Reference No.: A-401-1, A-401-2

Dear Mr. Tipton:

The following information summarizes the results we obtained from the McKenzie River water and the pumping pit samples collected by you and received in our laboratories on October 16, 1970.

McKENZIE RIVER WATER ANALYSIS

pH	6.7
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	30.0
Total Solids	56.0
Suspended Solids	2.0
Dissolved Solids	54.0
Calcium as Ca	4.0
Magnesium as Mg	3.0
Sodium as Na	5.0
Iron as Fe	1.2
Phosphate as PO_4	2.4
Chloride as Cl	1.1

Executive Offices
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Portland, Oregon

Canada
Continental Chemicals, Ltd.
Winnipeg, Manitoba

Australia
The Nightingale Supply Co., Ltd.
Sydney, N.S.W.

PUMPING PIT ANALYSIS

pH	6.7
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	40.0
Total Solids	56.0
Suspended Solids	4.0
Dissolved Solids	52.0
Calcium as Ca	5.0
Magnesium as Mg	4.0
Sodium as Na	5.5
Iron as Fe	1.0
Phosphate as PO_4	2.1
Chloride as Cl	1.8

NOTE: All of the above results are reported in milligrams per liter, except pH.

If we can be of further assistance to you concerning the analyses or evaluation of the above data, please ask.

Sincerely,

THE MOGUL CORPORATION

Lee Henry,
Director of Laboratories

LH/kmc

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

NORTHWEST DIVISION

[illegible] N. W. 31st AVENUE • PORTLAND, OREGON 97210 • TELEPHONE (503) 226-1461

MAR 22 1971

March 19, 1971

Vitro Hanford Engineering Services
2284 Oakmond Way
Eugene, Oregon 97401

Attention: Mr. Dick Tipton

Laboratory Reference No.: A-484-1, A-484-2, & A-484-3

Dear Mr. Tipton:

The following information summarizes the results we obtained from the McKenzie River water, pumping pit, and base sample north. These samples were collected by you and received in our laboratories on March 17, 1971.

MCKENZIE RIVER WATER ANALYSIS

pH	6.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	26.0
Total Solids	54.0
Suspended Solids	5.0
Dissolved Solids	49.0
Calcium as Ca	4.7
Magnesium as Mg	1.6
Sodium as Na	35.5
Iron as Fe	0.10
Phosphate as PO_4	0.23
Chloride as Cl	0.8

Executive Offices
20600 Chagrin Blvd.
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Minneapolis, Minnesota

Arlington, Texas
Phoenix, Arizona
Portland, Oregon

Canada
Continental Chemicals, Ltd.
Winnipeg, Manitoba

Australia
The Nightingale Supply Co., Ltd.
Sydney, N.S.W.

PUMPING PIT ANALYSIS

pH	6.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	20.0
Total Solids	59.0
Suspended Solids	8.0
Dissolved Solids	51.0
Calcium as Ca	5.5
Magnesium as Mg	1.6
Sodium as Na	35.5
Iron as Fe	0.15
Phosphate as PO_4	0.20
Chloride as Cl	1.6

BASE SAMPLE NORTH ANALYSIS

pH	6.5
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	20.0
Total Solids	352.0
Suspended Solids	155.0
Calcium as Ca	12.4
Magnesium as Mg	3.5
Sodium as Na	47.0
Iron as Fe	9.0
Phosphate as PO_4	2.45
Chloride as Cl	2.0
Dissolved Solids	197.0

Note: All of the above results are reported in milligrams per liter, except pH.

If we can be of further assistance to you concerning the analyses or evaluation of the above data, please ask.

Sincerely,

THE MOGUL CORPORATION

Lee Henry

Lee Henry,
Director of Laboratories

LH/kmc

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

NORTHWEST DIVISION

2852 N. W. 31st AVENUE • PORTLAND, OREGON 97210 • TELEPHONE (503) 226-1451

June 23, 1971

Vitro Corporation
204 Oakmont Building
2300 Oakmont Way
Eugene, Oregon 97401

Attention: Mr. Richard B. Tipton

Laboratory Reference No's: A-613-1,2,3, & 4

Dear Mr. Tipton:

The following information summarizes the results we obtained from the North Drain Line, South Drain Line, The McKenzie River, and Pumping Pit. These samples were collected by you and were received in our laboratories on June 16, 1971.

NORTH DRAIN LINE

pH	7.1
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	24.0
Total Solids	176.0
Suspended Solids	21.0
Dissolved Solids	155.0
Calcium as Ca	20.0
Magnesium as Mg	10.0
Sodium as Na	19.0
Iron as Fe	2.0
Phosphorus as P	0.313
Chloride as Cl	1.4
Ammonia (as N)	2.48

SOUTH DRAIN LINE

pH	7.4
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	24.0
Total Solids	164.0
Suspended Solids	16.0
Dissolved Solids	148.0
Calcium as Ca	15.0
Magnesium as Mg	10.0
Sodium as Na	14.5
Iron as Fe	2.0
Phosphorus as P	0.251
Chloride as Cl	1.5
Ammonia (as N)	3.10

THE MCKENZIE RIVER

pH	7.5
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	24.0
Total Solids	150.0
Suspended Solids	8.0
Dissolved Solids	142.0
Calcium as Ca	5.0
Magnesium as Mg	5.0
Sodium as Na	14.0
Iron as Fe	<0.1
Phosphorus as P	0.020
Chloride as Cl	0.7
Ammonia (as N)	0.08

PUMPING PIT

pH	7.1
P Alkalinity as $CaCO_3$	0.0

M Alkalinity as $CaCO_3$	24.0
Total Solids	46.0
Suspended Solids	6.0
Dissolved Solids	40.0
Calcium as Ca	5.0
Magnesium as Mg	5.0
Sodium as Na	13.0
Iron as Fe	<0.1
Phosphorus as P	0.020
Chloride as Cl	0.75
Ammonia (as N)	0.16

All of the above results are reported in milligrams per liter (mg/l), except pH.

If we can be of further assistance to you concerning the analyses, please ask.

Sincerely,

THE MOGUL CORPORATION

Lee Henry,
Director of Laboratories

LH/kmc

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

NORTHWEST DIVISION

2852 N. W. 31st AVENUE • PORTLAND, OREGON 97210 • TELEPHONE (503) 226-1451

JUL 30 1971

July 28, 1971

Vitro Corporation
204 Oakmont Building
2300 Oakmont Way
Eugene, Oregon 97401

Attention: Mr. Richard B. Tipton

Laboratory Reference Number: A-675

Dear Mr. Tipton:

The following information summarizes the results we obtained from the McKenzie River, the North Drain Line, the South Drain Line, and Pumping Pit. These samples were collected by you and were received in our laboratories on July 8, 1971.

THE McKENZIE RIVER

Ammonia (as N)	<0.2
pH	6.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	26.0
Total Solids	116.0
Dissolved Solids	113.0
Suspended Solids	3.0
Calcium as Ca	4.0
Magnesium as Mg	2.5
Sodium as Na	3.0
Phosphorus as P	0.016
Chloride as Cl	0.7
Iron as Fe	<0.05

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Winnipeg, Manitoba

Australia
The Nightingale Supply Co., Ltd.
Sydney, N.S.W.

NORTH DRAIN LINE

Ammonia (as N)	<0.2
pH	6.2
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	24.0
Total Solids	242.0
Dissolved Solids	218.0
Suspended Solids	24.0
Calcium as Ca	16.5
Magnesium as Mg	5.5
Sodium as Na	5.5
Phosphorus as P	0.248
Chloride as Cl	0.8
Iron as Fe	1.2

SOUTH DRAIN LINE

Ammonia (as N)	<0.2
pH	6.1
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	22.0
Total Solids	244.0
Dissolved Solids	240.0
Suspended Solids	4.0
Calcium as Ca	16.5
Magnesium as Mg	5.0
Sodium as Na	6.0
Phosphorus as P	0.294
Chloride as Cl	1.1
Iron as Fe	0.7

PUMPING PIT

Ammonia (as N)	<0.2
pH	6.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	28.0
Total Solids	188.0
Dissolved Solids	185.0
Suspended Solids	3.0
Calcium as Ca	4.5
Magnesium as Mg	4.5
Sodium as Na	3.5
Phosphorus as P	0.016
Chloride as Cl	1.6
Iron as Fe	<0.05

All of the above results are reported in milligrams per liter (mg/l), except pH.

If we can be of further assistance to you concerning the analyses, please ask.

Sincerely,

THE MOGUL CORPORATION

Lee Henry,
Director of Laboratories

LH/nv

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

NORTHWEST DIVISION

2852 N. W. 31st AVENUE • PORTLAND, OREGON 97210 • TELEPHONE (503) 226-1451

AUG 11 1971

August 9, 1971

Vitro Corporation
204 Oakmont Building
2300 Oakmont Way
Eugene, Oregon 97401

Attention: Mr. Richard B. Tipton

Laboratory Reference Number: A-707

Dear Mr. Tipton:

The following information summarizes the results we obtained from the McKenzie River, the Irrigation Water, the North Drain Line (Cold), and the South Drain Line (Warm). These samples were collected by you and were received in our laboratories on July 29, 1971.

THE McKENZIE RIVER

pH	7.3
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	30.0
Total Solids	54.0
Total Dissolved Solids	51.8
Total Suspended Solids	2.2
Chloride as Cl	1.5
Calcium as Ca	2.0
Magnesium as Mg	2.0
Sodium as Na	3.0
Phosphorus as P	0.03
Iron as Fe	0.15
Ammonia (as N)	<0.2

THE IRRIGATION WATER

pH	7.1
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	32.0
Total Solids	120.0
Total Dissolved Solids	119.0
Total Suspended Solids	1.0
Chloride as Cl	1.12
Calcium as Ca	2.5
Magnesium as Mg	2.0
Sodium as Na	3.5
Phosphorus as P	0.35
Iron as Fe	0.15
Ammonia (as N)	<0.2

THE NORTH DRAIN LINE (COLD)

pH	6.2
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	36.0
Total Solids	176.0
Total Dissolved Solids	170.2
Total Suspended Solids	5.8
Chloride as Cl	1.8
Calcium as Ca	7.5
Magnesium as Mg	5.0
Sodium as Na	6.25
Phosphorus as P	0.30
Iron as Fe	1.10
Ammonia (as N)	<0.2

THE SOUTH DRAIN LINE (WARM)

pH	5.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	28.0
Total Solids	174.0
Total Dissolved Solids	171.4
Total Suspended Solids	2.6
Chloride as Cl	1.35
Calcium as Ca	9.5
Magnesium as Mg	6.0
Sodium as Na	6.25
Phosphorus as P	0.42
Iron asFe	0.50
Ammonia (as N)	<0.2

All of the above results are reported in milligrams per liter (mg/ℓ), except pH.

If we can be of further assistance to you concerning the analyses, please ask.

Sincerely,

THE MOGUL CORPORATION

Lee Henry,
Director of Laboratories

LH/nv

WATER TREATMENT PRODUCTS AND SERVICES SINCE 1915

The MOGUL Corporation

NORTHWEST DIVISION

2852 N. W. 31st AVENUE • PORTLAND, OREGON 97210 • TELEPHONE (503) 226-1451

AUG 27 1971

August 25, 1971

Vitro Corporation
204 Oakmont Building
2300 Oakmont Way
Eugene, Oregon 97401

Attention: Mr. Richard B. Tipton

Laboratory Reference Number: A-726

Dear Mr. Tipton:

The following information summarizes the results we obtained from the Irrigation Line and the Filter Dam. These samples were collected by you and were received in our laboratories on August 12, 1971.

THE IRRIGATION LINE

pH	6.9
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	36.0
Total Solids	42.0
Total Dissolved Solids	41.4
Total Suspended Solids	0.6
Phosphorus as P	0.06
Chloride as Cl	3.9
Calcium as Ca	2.8
Magnesium as Mg	2.5
Sodium as Na	4.0
Ammonia as N	<0.2
Iron as Fe	0.10

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Sydney, N.S.W.

THE FILTER DAM

pH	7.1
P Alkalinity as $CaCO_3$	0.0
M Alkalinity as $CaCO_3$	32.0
Total Solids	56.0
Total Dissolved Solids	41.0
Total Suspended Solids	15.0
Phosphorus as P	0.07
Chloride as Cl	1.1
Calcium as Ca	3.0
Magnesium as Mg	2.5
Sodium as Na	4.1
Ammonia as N	<0.2
Iron as Fe	0.55

All of the above results are reported in milligrams per liter (mg/l), except pH.

If we can be of further assistance to you concerning the analyses, please ask.

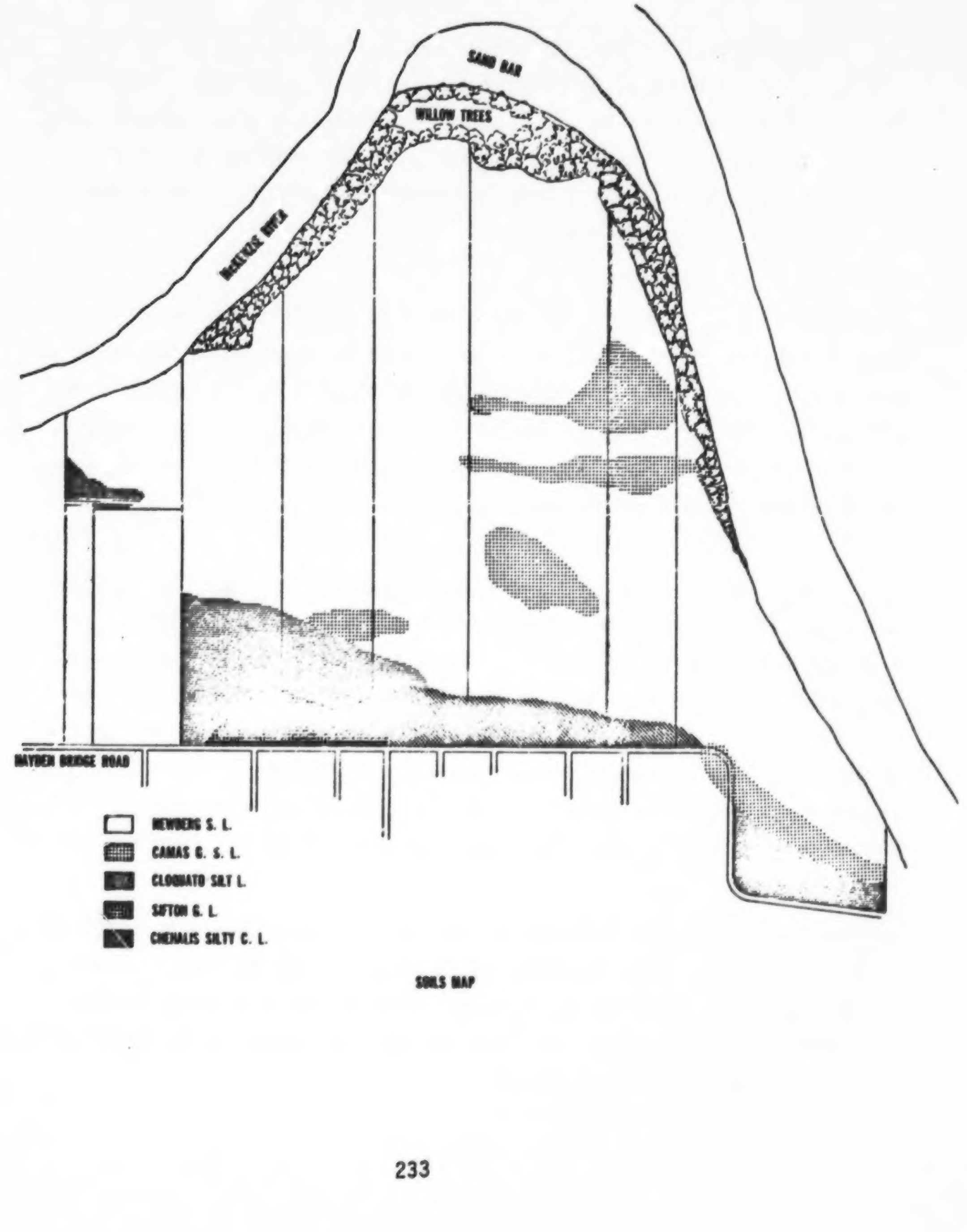
Sincerely,

THE MOGUL CORPORATION

John H. McDonald

John H. McDonald
Manager - Water Quality Services

JMD/nv


SAND BAR
WILLOW TREES
McKENZIE RIVER
HAYDEN BRIDGE ROAD
NEWBERG S. L.
CAMAS G. S. L.
CLOQUATO SILT L.
SIFTON G. L.
CHEHALIS SILTY C. L.

SOILS MAP

AREA WATER AND POWER REQUIREMENTS

The thermal power requirements of the region form the basis for the thermal water demonstration project at Springfield, Oregon. Power plants are designed to meet loads and conditions facing the power supply agencies at the time the plant is designed. The one settled on was to be rated at 1 million kW with a load factor of 80 percent. This plant would require a flow of 1420 cfs.

A million kW plant would raise the river water's temperature .3°F if the flow is 100,000 cfs. A detailed study would be required to estimate the effect of a large number of such plants if located on the Columbia and Willamette. For example, if one or two plants were built in Oregon using Columbia and Willamette flows, the indicated temperature rise would be 3°F when the flow in the Columbia below Portland is 100,000 cfs.

Raising the temperature of the Willamette and Columbia by the amount indicated is not permitted under current water-quality standards, and a relaxation of these standards probably will not occur. The present tendency is to make them more stringent. Three alternative solutions are: 1) assume plants will have cooling towers with consequent losses of water to evaporation; 2) assume plants will have a closed cooling system similar to an automobile radiator with only a minor loss of a makeup water; or 3) assume that heated water will be used for irrigation.

With induced-draft cooling towers, the cost of power will be increased by 5 to 15 percent over the cost where once-through cooling is used. No heat would be added to the stream. With a closed cooling system, the amount of makeup water required has been estimated to be about 1/10 or less of cooling tower requirements.

Use of heated water for irrigation would require application of effluent for 160 hrs per week throughout the growing season. Bypassing this continuous flow back into the river would not be permitted if, for some reason, the irrigation need fluctuated to a level considerably below the scheduled output. The flow in a once-through basis has been estimated to be 1300 cfs in the initial study of Washington's requirements, and the Portland General Electric Company has estimated a once-through flow of 2000 cfs would be required for its Trojan plant (1050 kW).

In the Willamette basin, the diversion rate for irrigation is 4.3 acre-ft per acre. Using a flow rate of 1600 cfs, one plant of 1 million kW capacity would furnish the diversion requirements for more than 110,000 acres, assuming a constant rate of diversion over the irrigation system. Some difficulties may be experienced in achieving a proper balance between irrigation development and low "growth" in power plants. Use of this solution also would unduly restrict the design of future generating plants.

Estimates of the cooling water evaporation loss by several agencies and authors cover a large range. They have been converted where necessary here to lbs of water per kW generation for ease of comparison. Burns and Roe, designers of the Fort Martin West Virginia plant (1,080,000 kW) state that 16 million gallons of water will be evaporated daily, equivalent to 5.6 lbs of water per kilowatt hour.

A joint power-planning council in April 1967 stated that the consumptive use would be 22 million gallons per day or per 1000 megawatts of installed capacity, and they also indicate that a plant factor is approximately equivalent to load factor at 90 percent. The consumptive use per kilowatt hour would be 8.5 lbs. Battelle Northwest indicates that the consumptive use of a 1 million kW plant with 80 percent plant factor would be 12,588 acre-ft, equivalent to 4.9 lbs per kilowatt hour. The engineering text Water Demands for Steam Electric Generation by Kootner and Loth, John Hopkins Press, 1965, states that minimal consumptive use requirements will decrease with the present .7 toward .5 gallons per kilowatt hour, equivalent to 5.8 to 4.2 lbs per kilowatt hour. From this stage in evaporation rates, a value of 5.6 lbs per kilowatt hour of generation is selected. This corresponds to an annual evaporation of 14,500 acre-ft for each standard size plant.

An advisory committee study indicates that a total of 109 plants each with a generating capacity of 1 million kW will be necessary to meet Oregon's load, and these have been assigned to various river basins. Generally in accord with projected 2070 population for the basin, the committee suggested that the environment be considered when locating thermal power plants; but no method of doing this by use of presently available climatic factors is feasible. Also, the science of predicting the effect that a cooling tower would have on the surrounding atmosphere, particularly the prediction of whether or not a detrimental fog condition would be created, has not been advanced to a readily usable state. Several sites should be investigated for each proposed plant and data on climatological factors pertaining to each site are vital.

An adjustment was made in the basins along the eastern and southeastern part of the state. These areas will be short of water when irrigable areas are developed and transportation of large heavy units for the construction of nuclear power plants will be difficult. All the required generation for these basins was assigned to plants below the John Day Basin. In July 1968, Eugene Water & Electric Board engaged Vitro Engineering to perform a feasibility study on the possibilities of utilizing water from a thermal plant that would meet necessary requirements. This report was completed and submitted to EWEB in September 1968.

Included in the feasibility study was the outlining of Vitro's capability to establish a program which would accommodate the climatological factors of the south Willamette Valley and to establish advantageous agricultural schemes to demonstrate the multi-use concept for eventual betterment of the 110,000 acres in the upper Willamette.

EWEB's consultants established a mathematical projection of utilization of cooling water and how it could be used for frost control, irrigation, and plant cooling. In addition, they established a rationale of environmental effect. The purpose of the atmospheric program is somewhat different than, but directly associated with, the demonstration farm and agronomic program. The atmospheric measurement would concentrate on micro-climatological effect rather than research or the development of techniques to answer two questions:

- How does the irrigation with warm water differ from irrigation with cold water with respect to influence on energy balance?
- If there is a significant difference between warm and cold water irrigation, what is its significance in terms of large and small scale climate modification?